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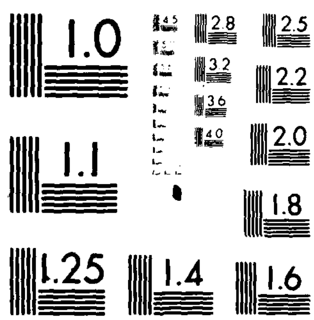

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Technical Report: NAVTRAEQUIPCEN IH-332

COMPUTER PROGRAM FOR ANALYSIS OF SPHERICAL SCREEN DISTORTIONS

Richard C. Hebb
ADVANCED SIMULATION CONCEPTS LABORATORY

March 1982

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NAVTRAEQUIPCEN IH-332

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Director, Research Department

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

In visual simulation, the distortion of imagery in wide-angle display systems is a major concern. Effective flight training requires that the imagery presented to a trainee provide a proper perspective view of his simulated environment without distortion. Use of spherical screens (domes) introduces perspective and geometrical distortion into these wide-angle displays. Use of video projection systems with Computer Image Generation (CIG) offers the options of raster shaping or computer remapping for distortion correction.

The method is to correct the imagery before projection in order to provide a "non-distorted" scene to a trainee. This report is documentation of a computer program for analysis of the required raster correction for specific projector/viewpoint positioning within a spherical screen. The programs and report were initiated to provide input to the F-18 simulator (Device 2E7) being developed by Hughes Aircraft.

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I. INTRODUCTION

Visual Flight Simulators

Visual Flight Simulators are used to enhance the training of pilots by adding visual cues to the simulated mechanical and physical aspects of a particular aircraft. The ultimate visual goal is to provide a realistic view of an environment about the simulated aircraft to increase training effectiveness.[1] Imagery is often provided by Computer Image Generation (CIG) and displayed via video projection systems. Typically the CIG system takes account of viewpoint and heading direction within a mathematically modeled landscape (database) to generate a view of this database during a simulated flight.[2] The imagery generated is in a video format, usually a 1023 line raster, and can be projected by light valves on the screen surface.[3] Image content depends on the database model and may include a horizon line. A trainee's view of this imagery, in conjunction with the aircraft dynamics and structure, can induce many physical/psychological effects of actual flight depending on the attention paid to modeling the actual aircraft and database.[4]

Wide-Angle Visual Displays

The goal of realism in visual displays has led to the use of very wide angle displays filling a horizontal field of view (FOV) of 90° or more at the pilot's viewpoint.[5] This has led to the use of spherical screens (domes) with a number of projectors filling parts of the FOV to form a wide-angle scene.[6] Ideally, the exit pupils of the projectors, along with the viewpoint, should be located at the center of the spherical screen to eliminate distortions. However, due to the physical structure of the simulated aircraft and the size of the projection systems, the exit pupils cannot all be placed at the screen center. Also, the viewpoint and projector exit pupils cannot coincide. Necessarily, this forces the oblique projection of the imagery onto the dome resulting in distortion of the imagery.

Distortion

Distortion refers to the geometry of an image as compared to the geometry of the objects involved. Perhaps the best way to describe the concept of distortion as related to optical systems is to consider first the concept of a distortionless lens mapping. Figure 1 shows the mapping process for a well corrected F Tan θ lens as a rectangular object is mapped through the lens. The resulting image formed on the image plane is again a rectangular figure. The radial distance, R, to an image point on this image plane is determined by the tangent of the angle that an object point subtends from the optical axis of the lens system. Hence, the lens mapping equation, $R = F \text{ Tan } \theta$, where F is the focal length of the lens. If the direction of the mapping process is reversed, we now have the case of the lens being used as a projection lens instead of use as a taking lens. For this case, any imagery placed on the image plane will be transferred to the object plane without distortion. This is the concept of a distortionless lens mapping.

Next, we should consider the concept of distortionless viewing of a projected image. If it were physically possible to place the eye of a viewer at the exit pupil of a F Tan θ lens as in Figure 2, then the viewer would perceive no distortion of the projected imagery. However, if the viewer's eye is removed from the exit pupil location, the shape of a rectangular figure would no longer appear rectangular. This removal of the eyepoint from the lens exit pupil results in a form of distortion known as Perspective Distortion, which usually results in rectangular objects exhibiting a keystone shape. The key to reducing Perspective Distortion is to place the exit pupil of the projector as close as possible to the viewer's eyepoint.

In a dome display system there exists another form of distortion. This form is labeled as Geometric Distortion, which involves the projection of imagery onto curved screen surfaces at oblique angles. The result is that the projection of straight lines onto the screen surface are viewed as being curved lines by the viewer. The amount of distortion produced depends on the size and shape of the screen, and projector/viewpoint positioning. As the viewpoint and/or the projector are displaced from each other, or removed from

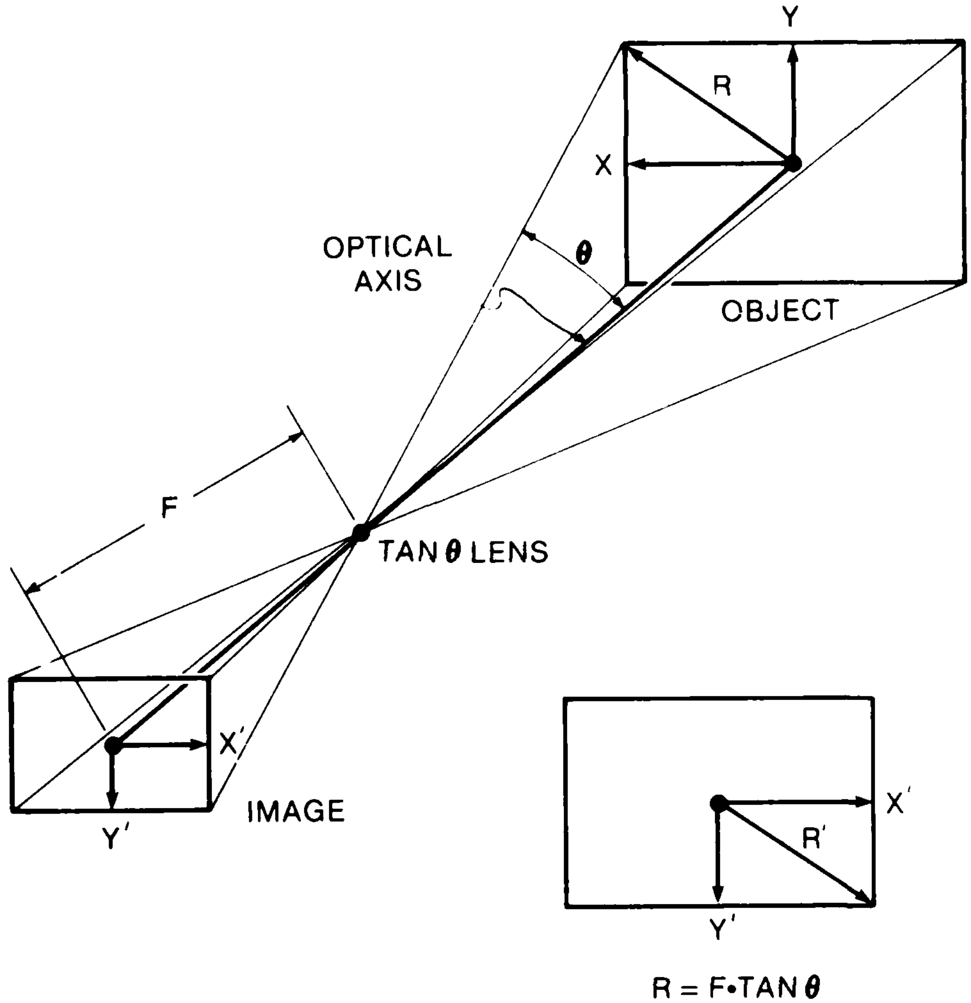

Figure 1. Mapping via Tangent Lens, Non-Distorted

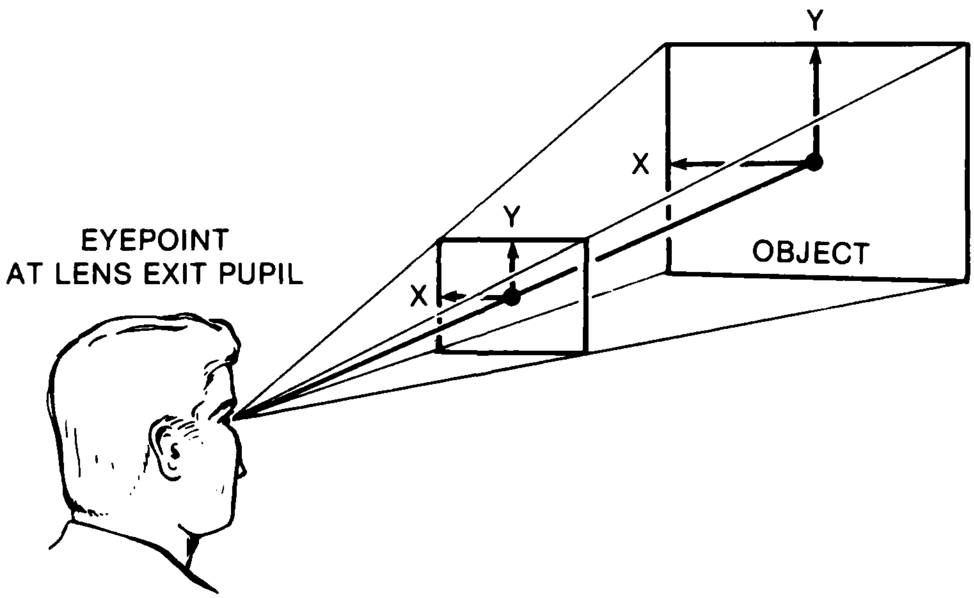

Figure 2. Distortionless viewing

the center of the screen, the apparent size and shape, as well as the angular subtense and position of objects will vary accordingly. It should be noted that if the viewpoint and lens exit pupil are coincident, then the shape of the screen cannot contribute to distortion[7]. It is the purpose of the computer program to be described to consider these two forms of distortion, Perspective and Geometric Distortion, in spherical screen displays.

Distortion definitions vary according to the type of projection system involved. The method of calculating distortion in this report is based on the Institute of Radio Engineers (IRE) Standards for Television.[8] This method defines the Geometric Position Error (GPE) for any point on a flat display screen as the magnitude of the distance from the point to its ideal location. This implies a radial distance measurement from the ideal location of a point to its actual position. The percentage of distortion is then found by dividing the GPE by the full field height of the image.

The use of video projection systems offers the option of correcting distortions by altering the scanning geometry of the video imaging system (i.e., raster shaping). In this way, the image can be pre-distorted (as compared to a rectangular raster) before projection, according to specific projector/viewpoint relationships, in order to produce a non-distorted view.[9] Alternately, the object points can be remapped in the CIG computation plane to provide the required object pre-distortion before being placed on the rectangular raster for projection. Raster shaping and remapping may be combined, if desired, to reduce the complexity of the individual corrections. These corrections must take into account the type of projection lens to be used and its inherent distortion, for the lens is an integral part of the system.

<u>Lens Mappings</u>

In the computer program that will be described there are four types of lens mappings considered for the projection lens. They are:

1. F Tan Θ (distortionless lens),

2. F Tan Θ with primary distortion,

3. F Θ,
4. F Sin Θ.

All these lens mappings imply a radially symmetric mapping, with the center of the mapping plane on the optical axis of the lens system. The F Tan Θ lens provides a one-to-one mapping from object space to image space with a magnification constant included. The F Tan Θ lens places an image point on the image plane according to the tangent of the angle between the optical axis and the object point. The F Tan Θ with Primary Distortion is defined as a departure from F Tan Θ due to an approximation of Tan Θ by only two terms of a power series, the resulting equation is:

$$R_p = R_t\ (1 + (\text{DFACTOR} * R_t^2)),$$

where R_p is the radial distance for the primary distortion mapping, R_t is the radial distance for Tan Θ mapping and DFACTOR is the primary distortion factor. An F Θ lens maps object space to image space according to the angle in radians to an object point from the optical axis, while the F Sin Θ implys a mapping according to the sine of the angle from the optical axis. Appendix B contains the derivation for the F Tan Θ mappings and the conversion to the three other mappings mentioned above.

For the points on these mappings, the angle from the optical axis of the projection lens can be found by calculating the radial distance to the point in question and then converting the radial distance to an angle depending on the type of mapping.

Figure 3 shows the mapping process for a F Tan Θ lens from the View Window on the dome, through the View Plane, and onto the Target Plane of the lens. The figure also depicts the viewpoint mapping of the View Window onto the Comparison Plane. This mapping produces a two-dimensional representation of the View Window as seen from the viewpoint.

The projection mappings produced by the program are mappings at the View Plane, which provide a perspective view of the object points on the dome from the projection point. A perspective view of the Target Plane from the

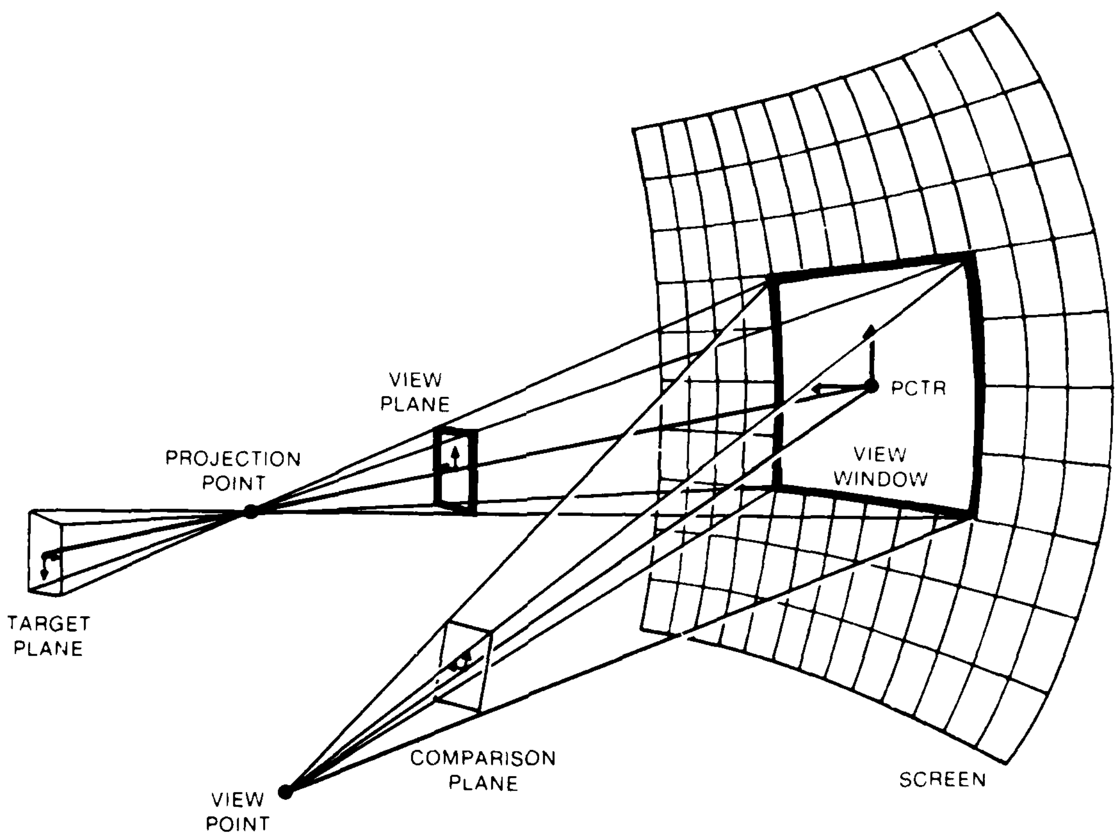

Figure 3. Projection/Viewing Diagram

projection point (a view of the required raster pattern) is obtained by a rotation of the mapping about its center by 180° and observing the pattern through the reverse side of the mapping. In all mappings, the value of F is considered to be unity, allowing mappings for a lens of focal length f^1 to be represented by multiplying the mapping point coordinates by f^1.

The Comparison Plane is a perspective view of the View Window from the viewpoint and contains the image of the non-distorted reference raster which has been placed on the View Window. Use of the Comparison Plane coordinates requires the scaling of the coordinates to reduce the Comparison Plane's height to the height of the View Plane. The scaling factor is defined as the ratio of the View Plane height to the Comparison Plane height. For purposes of distortion calculations in the program to follow, the GPE is found by effectively overlaying the View Plane on the Comparison Plane via coordinate tables for the planes. The distance from a point on the Comparison Plane (XC, YC) to a point on the View Plane (X, Y) is found via the equation:

$$D = [(X - XC)^2 + (Y - YC)^2]^{1/2}.$$

II. THE PROGRAM - MAPTAG

Introduction

MAPTAG is an acronym for Mapping Table and Graph, a program written in FORTRAN for distortion analysis. The facilities for operation of the program are part of the NAVTRAEQUIPCEN Computer Systems Laboratory. The computer system is a VAX-11/780 with graphics provided on a Tektronix graphic terminal, Model 4014-11. The program is designed to find the required distorted raster shape for projection onto a dome from a particular projection point. This projected raster is to be viewed at a viewpoint as a non-distorted raster. The location of the viewpoint and projector can be located inside or outside the dome of radius R. The raster to be viewed is created as an Input Plane with variable height and width, as required, to fill a desired vertical and horizontal angular field relative to the viewpoint. This Input Plane is subsequently mapped on the surface of the dome to provide the View Window.

In order to describe the projection/viewing system, the location of the projector, viewpoint, and image points are referenced to a 3-D coordinate system located at the center of the dome (Figure 4). In this system, the Z-axis is positive upwards, the X-axis is positive forward, and the Y-axis is positive to the left. Additionally, the angles for projection and viewing are spherical angles referenced to the positive X-axis. Vertical angles are positive above the dome horizon and negative below the horizon with a maximum magnitude of 90°. Horizontal angles are positive for a counter-clockwise rotation (positive X-axis into the positive Y-axis) when viewed from a point on the positive Z-axis. The horizontal angles have a maximum magnitude of 180°. There are three other coordinate systems involved in the program. These are two 3-D coordinate systems, located at the viewpoint and projection point, and a 2-D coordinate system used to describe the raster plane defined as the Input Plane. This plane is used to provide a non-distorted raster pattern for comparison purposes.

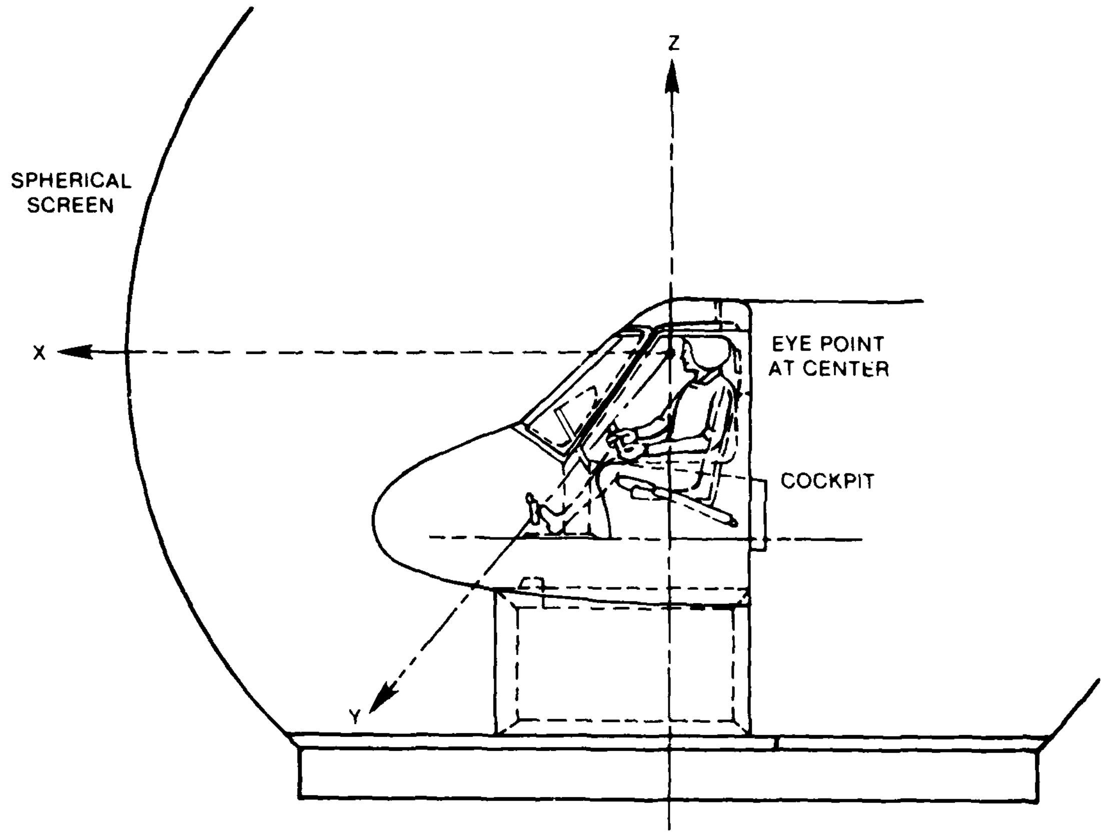

Figure 4. 3-D Coordinate System For Spherical Screen

View Window

The View Window is defined as that part of the available FOV that is being filled by one projector. Ideally, the viewer will see objects projected onto this window as non-distorted. If a crosshatch pattern is the projected object, then the viewer will want to see the crosshatch pattern with equal spacing between the horizontal and vertical lines on the view window. This is the Input Plane and is constructed by considering the desired angular height and width as well as the position of the center of the view window (PCTR) relative to the viewpoint. These values are used to find the height and width of the crosshatch pattern in dimensional units that are fixed with respect to dimensional units used for all 3-D locations.

The Input Plane has a 2-D coordinate system with its origin set at the center of the plane (Figure 5). In this coordinate system the Y-axis is positive upward and the X-axis is positive to the left. Once the height and width of the Input Plane are known, then the first point on the plane is found by dividing the height and width in half. This first point is defined as the top left point on the plane. Subsequent points on the plane are found by considering the number of horizontal lines (NHORIZ) and the number of vertical lines (NVERT) on the plane. The width of the plane is divided by (NHORIZ-1) to find the linear increments along the lines (HINCREMENT), while the height is divided by (NVERT-1) to find the linear increments between lines (VINCREMENT). To find the next point along a line on the plane, the HINCREMENT is subtracted from the previous points' X-coordinate with the Y-coordinate remaining the same. At the end of a line, the VINCREMENT is subtracted from the previous points' Y-coordinate, and the X-coordinate is reset to the X-coordinate of the first point. In this way, lines are drawn from left to right and top to bottom on the Input Plane.

After a point on the Input Plane is found, the Input Plane is aligned to be normal to the viewers' Line of Sight (LOS) and translated to the desired View Window center (Figure 6). This operation is performed by the subroutine TROPLN (see Appendices). At this point, the View Window is projected onto the surface of the spherical screen but still appears to be a flat non-distorted raster from the viewpoint.

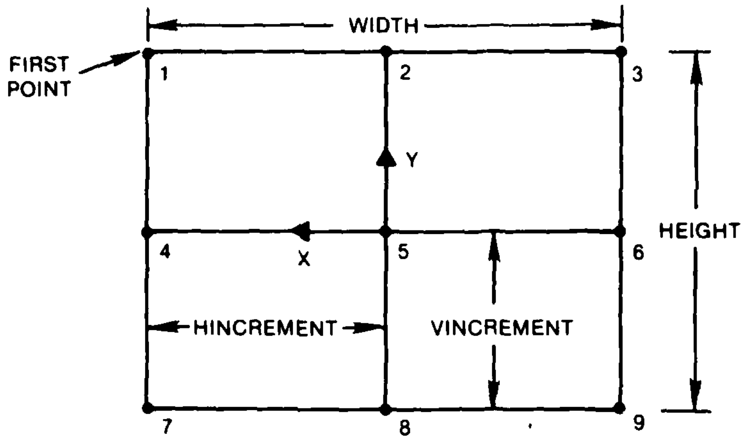

Figure 5. 3x3 Input Plane

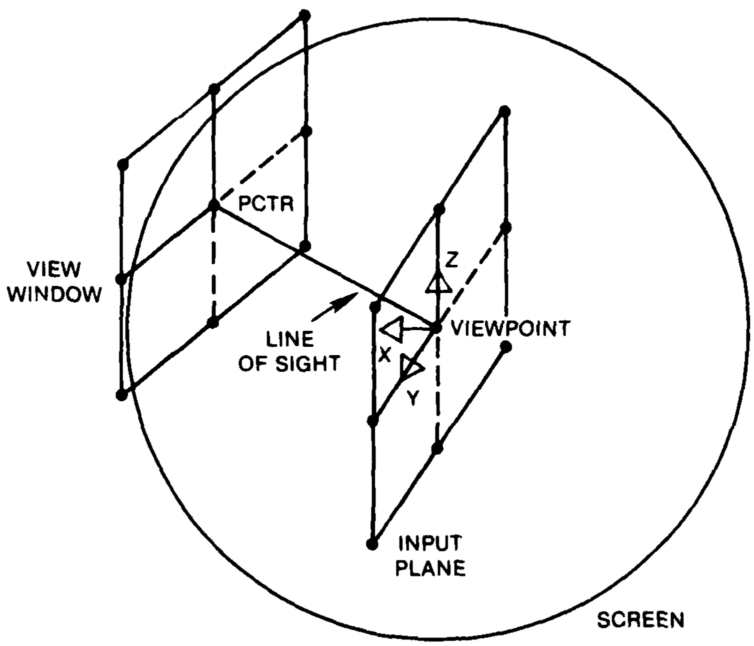

Figure 6. View Window Generation

Spherical Screen Projection

To find the intersection of a ray projected from the viewpoint towards the spherical screen, the subroutine SPTFAN "Sphere Point from Angles" is used. This subroutine uses spherical angles of projection to define the direction of individual rays at the viewpoint. This distance from the viewpoint to the screen is calculated and used to find the terminus of the ray in 3-D coordinates.

The angles to points on the View Window plane from the viewpoint are found by subroutine SANGFPT "Spherical Angles from Points" and then are input to SPTFANG. The View Window is then mapped onto the screen surface and we are now ready to find a perspective view of the View Window from the projection point.

Perspective View

Another subroutine, PSPECTIVE, is used to find the perspective view of the View Window from the projection point. Initially, the subroutine translates the origin of the 3-D coordinates for the View Window to the projection point. Then, the View Window is rotated about the projector to align the center of the View Window (PCTR) with the projector's X-axis. Having accomplished these operations, the tangents to points on the View Window can be found relative to PCTR.

PSPECTIVE allows this tangent mapping to be altered by a remapping through one of the three other lens mappings listed previously. Only the tangent mappings will give a correct perspective from the projection point, with the three additional mapping choices distorting the view according to their mapping functions. These mapping coordinates are sent to plotting programs which draw the View Plane on a graphic terminal with hard-copy available.

Reference circles, indicating total Fields-of-View (FOV) of 90° and 110°, are included on the output mappings. These FOV are generated by subroutine FOV and are dependent on the type of lens mapping specified. These reference circles can be used to determine the location of object points relative to the optical axis of the lens. Points that lie on a circle are defined as being located at the half-angle of the total FOV. For example, if a point is on the 90° FOV circle, then the angle between the optical axis and the ray to that point is 45°. Points outside the FOV reference circle are at greater angles, while points inside the FOV reference angles are at an angle less than the FOV half-angle. The FOV reference circles give an excellent way to approximate the total FOV required for a particular projection arrangement.

Mapping Tables

The coordinates for the View Plane output mapping can also be placed in table form. Each table contains specific information on the projection/viewing system and the type of mapping used. The coordinates are printed in the table according to their relative position on the view plane. Also placed in the table output are the coordinates of the Comparison Plane, allowing distortion calculations to be made from the table. If table output is desired, only 12 horizontal points should be requested on the crosshatch pattern. This limit is due to the fixed width of the printer paper and the width of numerals for each coordinate value in the table.

Subroutine TBLDIST uses the coordinates sent to the mapping tables to calculate distortion percentages for nine points in the field. These nine points, assuming an odd number of points on the plane, are the four corner points, the central point, and the four points at the midpoint of each edge of the plane. The percentages found are included on the mapping table output.

III PROGRAM OPERATION

Running the Program

In order to operate the program, variables describing the projection/viewing system must be entered. Upon instructing the computer to execute the program (RUN MAPTAG), the user is prompted to enter the necessary values. Definition of the view window starts with the location of the center of the view window (PCTR). This location is in 3-D coordinates relative to the screen center and must be on the screen surface. Next, the height and width in degrees and the number of points across and down the window are entered. The maximum height or width of the window is less than 180° due to the method of creating the input plane. Additionally, the number of points should be odd for use in the distortion calculation subroutine.

Describing the rest of the system requires entering the radius of the screen (R), the projector location EX(FX, FY, FZ), and the viewpoint, EN(XE, YE, ZE). The units for these coordinates are arbitrary, but must the same for all 3-D coordinates. As an option, the projector axis can be offset from PCTR during operation of the program by entering degree offsets other than zero for VOFFP and HOFFP.

The rest of the values to be entered are concerned with the type of output mapping and table. The type of lens mapping is chosen by entering a value from 1 to 4 corresponding to the four lens mappings available. If a Tan θ mapping with a primary distortion is desired, then the user is prompted to enter a distortion factor (DFACTOR). Additionally, for initialization of the graphics terminal screen, the user is instructed to enter a graphic scaling factor (FSCALE), screen magnification factor (SMAG), and offsetting values for the origin of the screen (XBIAS, YBIAS) in inches. Finally, the user can decide if table output is wanted during the present run of the program.

After the program has completed the graphics, the user is instructed to enter "C" to continue execution. The user is then offered the option of changing the projection axis offset, graphic scaling, graphic screen magnification, and table output option. If a change is desired, the program again prompts the user to enter values and the graphic screen is cleared in order to draw a new perspective view according to the new values. If no changes are desired, the program will clear the graphic screen and execution is stopped.

Sample Projection Systems

As examples, the results of two sample projection/viewer systems are included in the Appendices. The first sample is a simple projector/viewer arrangement where the viewer is placed at the center of a 20-foot radius dome and the projector is located at the 3-D location (0.0, 0.0, 12.0) inches. This results in a 12-inch displacement of the projector directly above the viewer. In this case, the projected View Window subtends angles of 70° vertical by 90° horizontal from the viewpoint. On this View Window, there is an 11 by 11 raster pattern which forms one hundred rectangular blocks as depicted on Figure A-1. The window is centered on the surface of the dome at the 3-D location (240.0, 0.0, 0.0) inches, or at the intersection of the X-axis with the dome surface. Table A-1 shows the program prompts and user inputs to describe the above system. Figures A-2, A-3, and A-4 show the required raster shapes to be projected from the defined projector location for the use of projection lenses with mapping functions of Tan Θ, Sin Θ, and Θ, respectively.

The second projection/viewer arrangement is a projector arrangement with the View Window and projector located on opposing sides of the dome surface. In this system, the viewpoint is again coincident with the center of a 20-foot radius dome. However, the projector is located behind the viewer on the surface of the dome at the 3-D location (-218.0, 0.0, 101.0) inches, and the View Window is placed at the 3-D location (218.0, 0.0, -101.0) inches. This arrangement directs the optical axis of the projector to pass through the center of the dome on its way to the center of the View Window, and provides for a symmetrical projection onto the window at a distance of twice the dome radius, or 40 feet. The View Window contains an 11 by 11 raster pattern and subtends angles of 160° by 160° from the viewpoint as shown in Figure A-5. Figures A-6, A-7, and A-8, with Tables A-6, A-7, and A-8, describe the required raster shapes for Example 2. Table A-5 shows the necessary inputs to describe this second system.

Analysis of the Sample Systems

Analysis of the required raster shapes for a projection system involves looking at the graphic mapping outputs and their corresponding table outputs. From these a visualization of the raster shapes is obtained, along with the distortion percentages related to each mapping.

Examining the coordinate tables A-2, A-3, and A-4, which are for the first example, specific information for each type of lens in this projection arrangement is revealed. The tables are labeled as to the type of lens mapping function considered along with identification of the projector, viewer, and View Window locations. The tables contain the coordinates of the intersection points for the distorted raster shape and the coordinates of the non-distorted Comparison Plane. Notice that the coordinates are preceded by the labels (X, Y) and (XC, YC) which denote the coordinates of the view plane and Comparison Plane, in turn. These coordinates are included in the tables in the same manner that the raster lines are drawn on the View Window; that is, left to right and top to bottom. The tables provide only the coordinates of the points used in the distortion calculation routine, and not all the points of the 11 by 11 pattern. The coordinates of all the points are available, but are not included here due to the size of the tables.

The first output mapping for Example 1, Figure A-1, is a tangent mapping of the View Window, or equivalently, the Comparison Plane. This is the raster shape that the viewer should see for the condition of no distortion. The tangent mapping for this projection system, Figure A-2, shows a maximum distortion of 2.6 percent, with symmetrical distortion about the center vertical line of the raster pattern. All the distortion percentages for this mapping are low and reflect the close proximity to the viewpoint of a projector with a F Tan Θ mapping function. Looking at the F Θ and F Sin Θ outputs, the maximum distortion percentages jump to 15.7 percent and 20.3 percent. These percentages are large and reflect the departure of the individual lens mapping functions from a distortionless, or F Tan Θ, lens. In this system, a lens with a F Tan Θ mapping would be preferred due to the closeness of the projector and viewer, and the less than 90° projection angles required.

The second example is offered as an extreme case compared to the preceding case. The separation of the projector and viewer is increased to 20 feet and the View Window is required to fill a field of view of 160° by 160° at the viewpoint. Examining the mappings and tables for this second system, it can be seen that the distorted raster shapes for all the mapping functions fall within the 90° reference circle. In fact, the maximum projection angle for any of the lenses is approximately 80°. This angle is appropriate considering the View Window to fill a 160° by 160° field of view at the viewpoint with projection from a distance of twice the dome radius. A projection lens with a total field of view of 90° would provide more than enough of the projection field required to fill the View Window.

The distortion percentages for all three lens types are quite large and are approximately equal. Examining Tables A-6, A-7, and A-8, the maximum distortion required for the F Θ mapping is slightly greater than the tangent mapping (18.09 percent vs. 18.90 percent), while the F Sin Θ mapping requires the most raster shaping at 19.22 percent. These raster shapes may be hard to implement by raster shaping alone as can be seen in Figures A-6, A-7, and A-8.

Other information to be gained from the program output concerns the re-distribution of the raster points on the projection lens target plane. In the second system, the points are crowded together near the edges of the target plane with only a few points in the center of the target plane. The effect of this distribution depends on the projection lens in use, but would tend to reduce the resolution capacity of the imaging system. This is due to the crowding of resolution elements (RESELS) on the target plane where most lenses lose resolution capability, and lack of RESELS where most lenses have their greatest resolution.

IV SUMMARY

The program MAPTAG is a very useful tool for determining the required raster shape to be projected which provides for distortionless viewing. The graphic output provides visualization of distortions encountered in spherical screen projections. The table output allows distortion calculations to be performed and can also provide for equations that describe the raster distortion, line by line. The subroutines used by MAPTAG have been written in general form to allow their use in building other specific distortion routines.

Extension of the program to provide more information about projection systems is possible and is being investigated. These programs provide an excellent basis for distortion analysis of video projection systems and efforts are being taken to include projection of generalized imagery. Additionally, the type of screen surface used in the program is being expanded to include cylindrical screens.

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APPENDICES

EXAMPLE 1

```
RUN MAPTAG

    DESCRIBE PLANAR INPUT SCREEN

    ENTER DESIRED COORDINATES FOR PLACEMENT OF CENTER OF PLANE IN SPHERE
    COORDINATE SYSTEM, THE X-AXIS IS POSITIVE FORWARD WITH THE Y-AXIS POSITIVE
    TO THE LEFT, AND THE Z-AXIS IS POSITIVE UPWARDS
240,0,0

    ENTER VERTICAL AND HORIZONTAL FOV'S IN DEGREES
70,90

    ENTER NUMBER OF POINTS ALONG VERTICAL AND HORIZONTAL AXES
11,11

    DESCRIBE SPHERICAL SCREEN DISPLAY SYSTEM

    ENTER SPHERICAL SCREEN RADIUS
240
    ENTER PROJECTOR POSITION (FX,FY,FZ)
0,0,12
    ENTER VIEWPOINT POSITION (XE,YE,ZE)
0,0,0
    ENTER VERTICAL AND HORIZONTAL OFFSET FOR PROJECTION DIRECTION (DEGREES)
0,0
    ENTER SCALE FACTOR , SCREEN MAG , YBIAS, XBIAS
     NORMALLY SCREEN MAG = 1.   ,XBIAS = 0.,YBIAS = 0,
     THE SCALE FACTOR DETERMINES THE TFOV (FSCALE * 90)
1,5,1.1,0.0
    PICK WHICH TYPE OF MAPPING DESIRED, FOR A TANGENT MAPPING ENTER "1" ,
    FOR AN IDEAL R-THETA MAPPING ENTER "2" , FOR TANTHETA MAPPING WITH
    PRIMARY DISTORTION , ENTER "3" ,FOR SIN THETA MAPPING, ENTER "4"
1
    IF TABLE OUTPUT IS DESIRED TYPE TRUE ; IF NOT FALSE
T
    TYPE C TO CONTINUE EXECUTION
1
$   C
 TO CHANGE VOFF,HOFF,MAG,FSCALE,LTABLE,TYPE OF MAPPING ENTER "T" , IF NOT
  ENTER "F"
F
    TO CHANGE SCREEN MAGNIFICATION,ENTER T ,TO STOP ENTER F
F
FORTRAN STOP
$
```

TABLE A-1

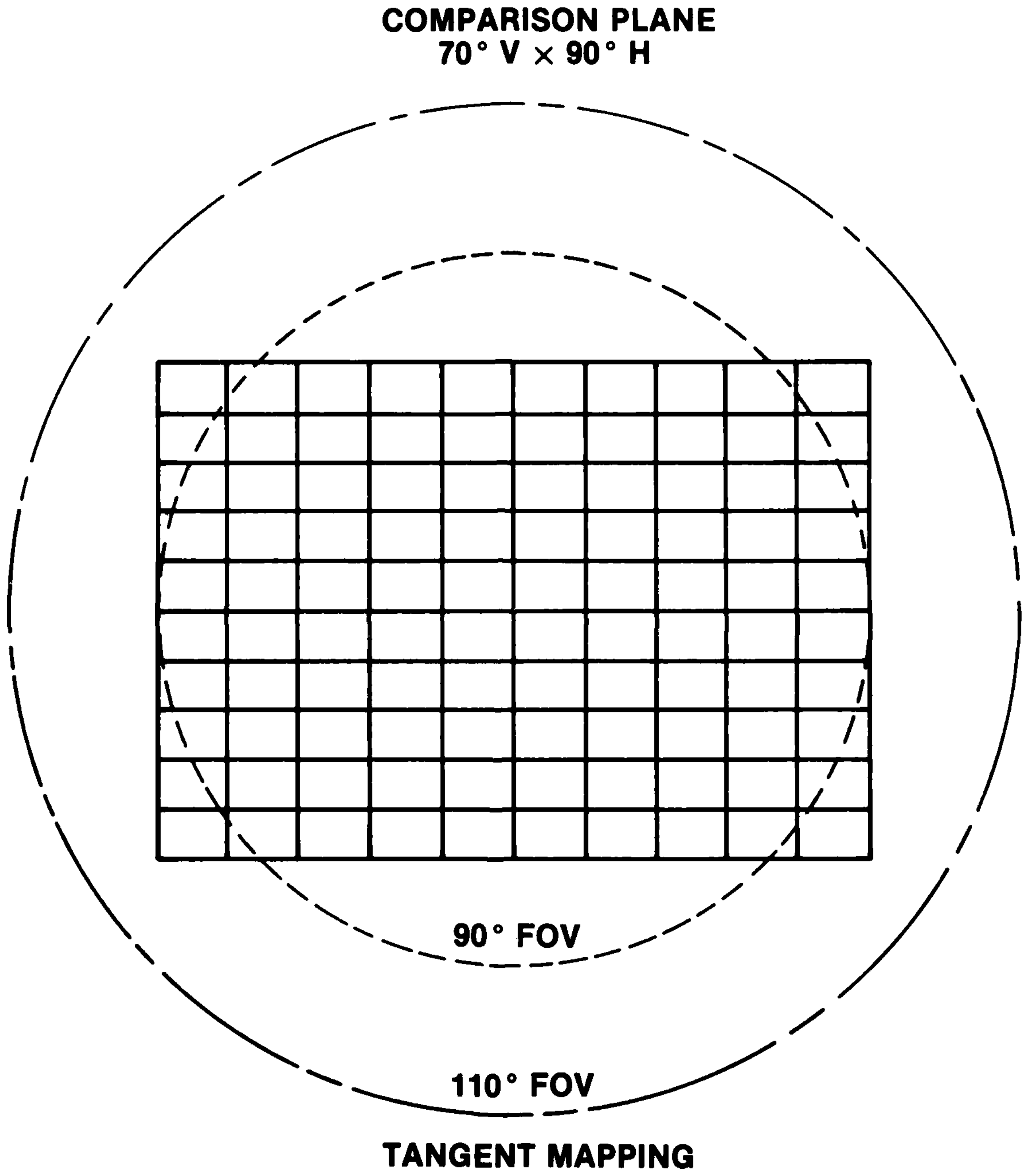


Figure A1. Tangent mapping.

TAN THETA MAPPING COORDINATES

THE VIEWPOINT IS AT :
X = 0.000   Y - 0.000   Z = 0.000
OBSERVING A LINEAR RASTER PATTERN ON THE SCREEN FILLING A FIELD OF 70.000 DEGREES VERTICALLY, AND 90.000 DEGREES HORIZONTALLY ABOUT A POINT X= 240.000 Y = 0.000 Z= 0.000 DEFINED AS CENTER OF "FOV".

THE PROJECTOR IS AT:
X = 0.0000 Y = 0.000 Z = 12.000
THE PROJECTION DIRECTION IS OFFSET BY V= 0.000 H = 0.000 FROM THE DEFINED FOV CENTER.

THE RADIUS OF THE SPHERICAL SCREEN IS 240.000

X	1.033	0.000	-1.033
Y	0.693	0.712	0.693
XC	1.000	0.000	-1.000
YC	0.700	0.700	0.700
X	0.998	0.000	-0.998
Y	-0.021	0.000	-0.021
XC	1.000	0.000	-1.000
YC	0.000	0.000	0.000
X	0.964	0.000	0.964
Y	-0.702	-0.685	-0.702
XC	1.000	0.000	-1.000
YC	-0.700	-0.700	-0.700

DISTORTION PERCENTAGES

THE TARGET PLANE HEIGHT IS 1.397

1	2	3
2.59%	0.96%	2.59%
4	5	6
1.48%	0.00%	1.48%
7	8	9
2.44%	0.96%	2.44%

TABLE A-2

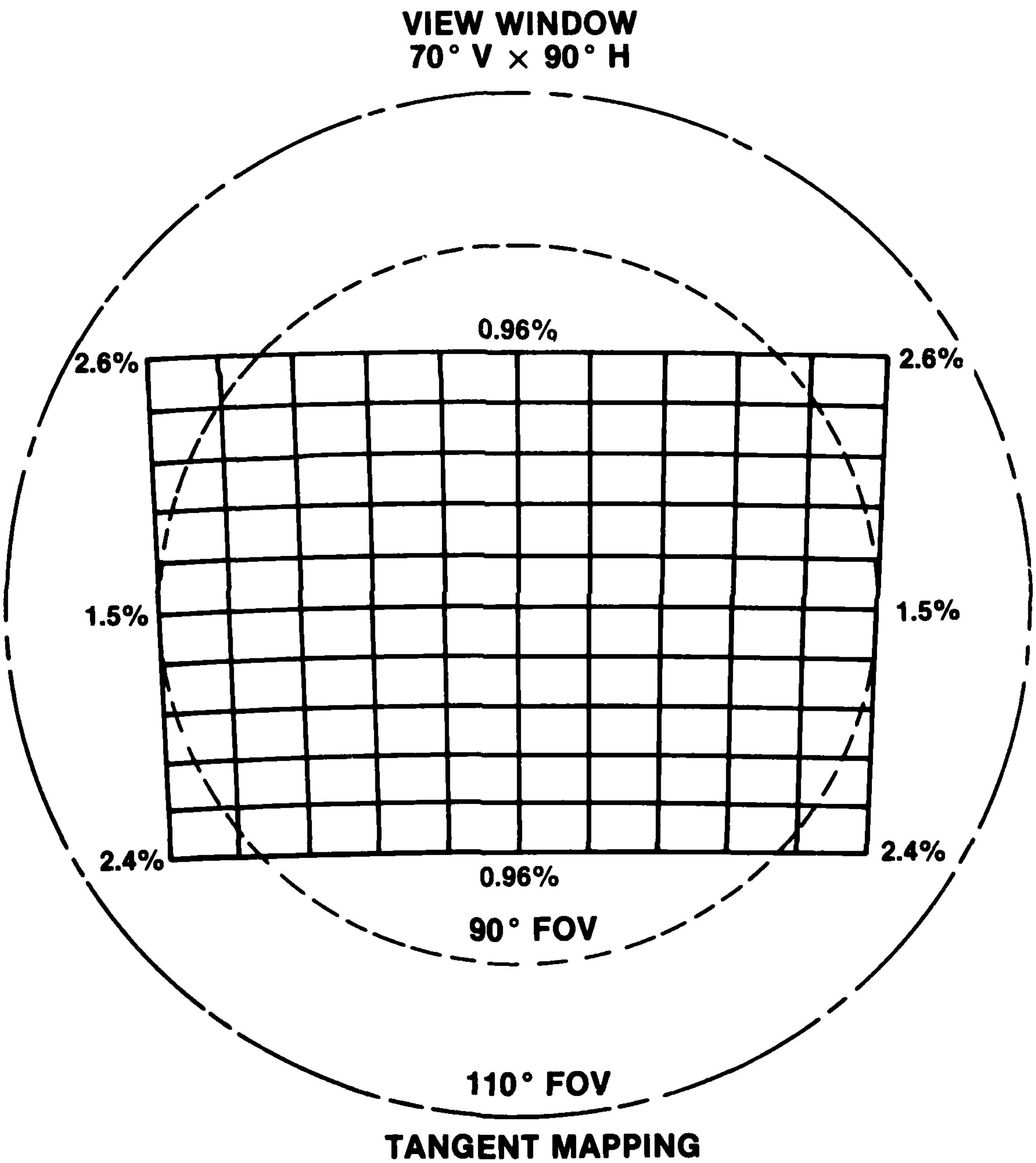


Figure A2. Tangent mapping.

R-THETA MAPPING COORDINATES

THE VIEWPOINT IS AS :
X = 0.0000 Y = 0.000 Z = 0.000
OBSERVING A LINEAR RASTER PATTERN ON THE SCREEN FILLING A FIELD OF 70.000 DEGREES VERTICALLY, AND 90.000 DEGREES HORIZONTALLY ABOUT A POINT X= 240.000 Y= 0.000 Z= 0.000 DEFINED AS CENTER OF "FOV".

THE PROJECTOR IS AT :
X = 0.0000 Y = 0.000 Z = 12.000
THE PROJECTION DIRECTION IS OFFSET BY V= 0.000 R = 0.000 FROM THE DEFINED FOV CENTER.

THE RADIUS OF THE SPHERICAL SCREEN IS 240.000

X	0.742	0.000	-0.742
Y	0.498	0.619	0.498
XC	1.000	0.000	-1.000
YC	0.700	0.700	0.700
X	0.784	0.000	-0.784
Y	-0.016	0.000	-0.016
XC	1.000	0.000	-1.000
YC	0.000	0.000	0.000
X	0.706	0.000	-0.706
Y	-0.514	-0.601	-0.514
XC	1.000	0.000	-1.000
YC	-0.700	-0.700	-0.700

DISTORTION PERCENTAGES

THE TARGET PLANE HEIGHT IS 1.219

1	2	3
13.97%	0.74%	13.97%
4	5	6
7.22%	0.00%	7.22%
7	8	9
15.66%	0.74%	15.66%

TABLE A-3

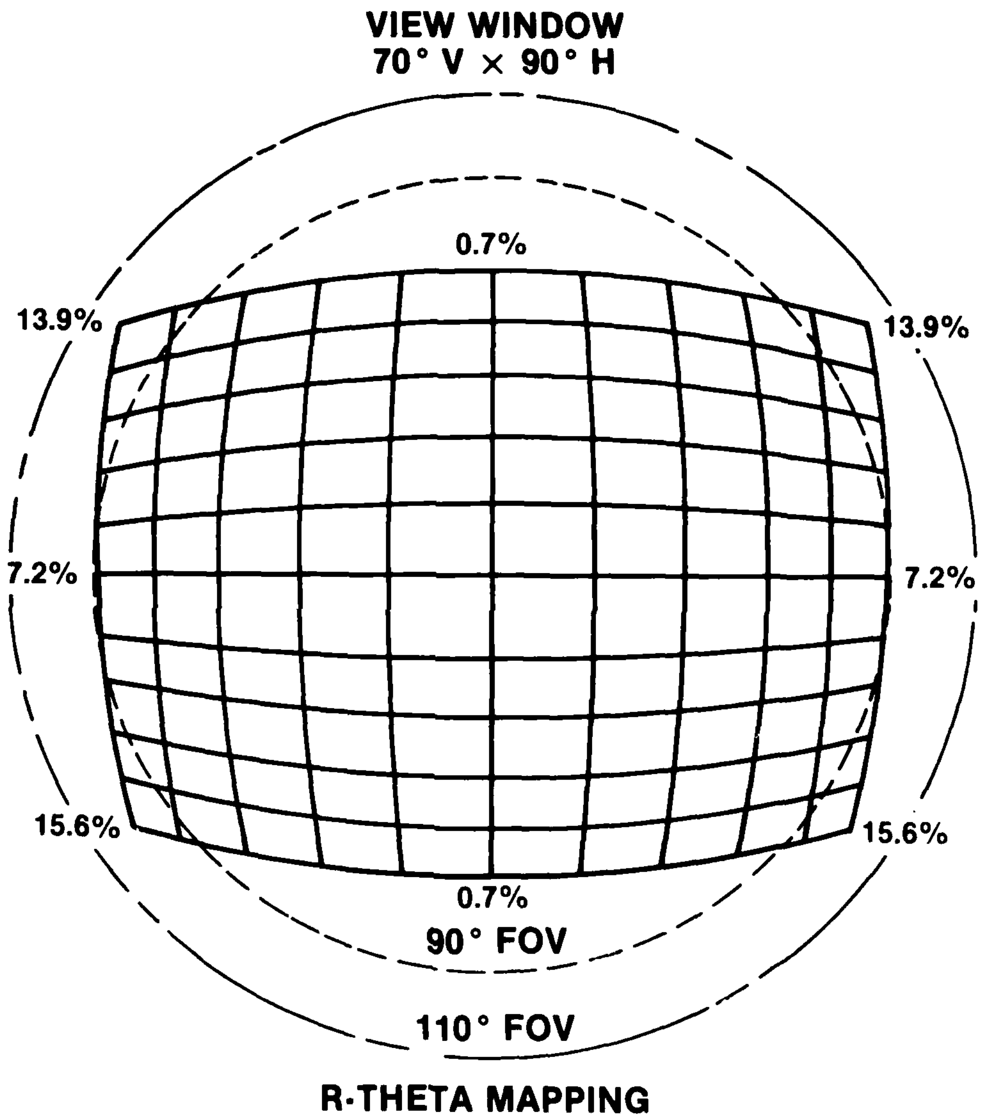


Figure A-3. R-Theta Mapping.

SIN THETA MAPPING COORDINATES

THE VIEWPOINT IS AT :
X = 0.0000 Y = 0.000 Z = 0.000
OBSERVING A LINEAR RASTER PATTERN ON THE SCREEN FILLING A FIELD OF 70.000 DEGREES VERTICALLY, AND 90.000 DEGREES HORIZONTALLY ABOUT A POINT X= 240.000 Y= 0.000 Z= 0.000 DEFINED AS CENTER OF "FOV".

THE PROJECTOR IS AT :
X = 0.0000 Y = 0.000 Z = 12.000
THE PROJECTION DIRECTION IS OFFSET BY V= 0.000 H = 0.000 FROM THE DEFINED FOV CENTER.

THE RADIUS OF THE SPHERICAL SCREEN IS 240.000

X	0.647	0.000	-0.647
Y	0.434	0.580	0.434
XC	1.000	0.000	-1.000
YC	0.700	0.700	0.700
X	0.706	0.000	-0.706
Y	-0.015	0.000	-0.015
XC	1.000	0.000	-1.000
YC	0.000	0.000	0.000
X	0.619	0.000	-0.619
Y	-0.451	-0.565	-0.451
XC	1.000	0.000	-1.000
YC	-0.700	-0.700	-0.700

DISTORTION PERCENTAGES

THE TARGET PLANE HEIGHT IS 1.145

1	2	3
19.17%	0.64%	19.17%
4	5	6
9.82%	0.00%	9.82%
7	8	9
20.32%	0.64%	20.32%

TABLE A-4

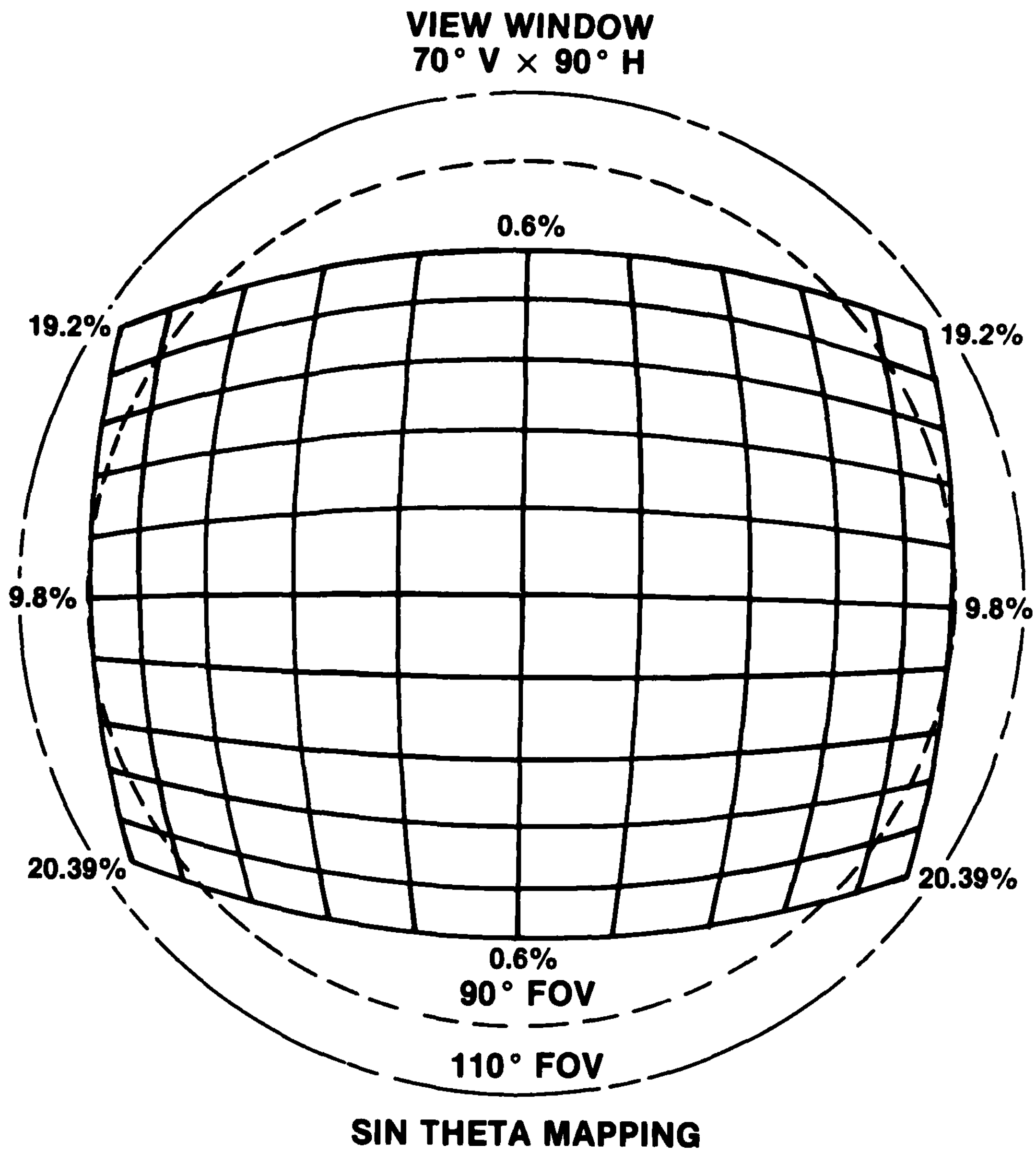


Figure A-4. Sin Theta Mapping.

EXAMPLE 2

SAMPLE RUN OF MAPTAG

```
RUN MAPTAG
  DESCRIBE PLANAR INPUT SCREEN

  ENTER DESIRED COORDINATES FOR PLACEMENT OF CENTER OF PLANE IN SPHERE
  COORDINATE SYSTEM .THE X-AXIS IS POSITIVE FORWARD WITH THE Y-AXIS POSITIVE
   TO THE LEFT, AND THE Z-AXIS IS POSITIVE UPWARDS

218,0,-101

    ENTER VERICAL AND HORIZONTAL FOV'S IN DEGREES

160,160

    ENTER NUMBER OF POINTS ALONG VERTICAL AND HORIZONTAL AXES

11,11

    DESCRIBE SPHERICAL SCREEN DISPLAY SYSTEM

    ENTER SPHERICAL SCREEN RADIUS

240
    ENTER PROJECTOR POSITION (FX,FY,FZ)

-218,0,101
    ENTER VIEWPOINT POSITION (XE,YE,ZE)

0,0,0
    ENTER VERTICAL AND HORIZONTAL OFFSET FOR PROJECTION DIRECTION (DEGREES)

0,0
    ENTER SCALE FACTOR , SCREEN MAG , YBIAS, XBIAS   NORMALLY SCREEN MAG = 1.
     ,XBIAS = 0.  ,YBIAS = 0.  THE SCALE FACTOR DETERMINES THE TFOV (FSCALE
     * 90)
1.5,1,0,0
    PICK WHICH TYPE OF MAPPING DESIRED, FOR A TANGENT MAPPING ENTER "1" , FOR
    AN IDEAL R-THETA MAPPING ENTER "2" , FOR TANTHETA MAPPING WITH PRIMARY
    DISTORTION , ENTER "3" ,FOR SIN THETA MAPPING, ENTER "4"

1
    IF TABLE OUTPUT IS DESIRED TYPE TRUE ; IF NOT FALSE
T
    TYPE C TO CONTINUE EXECUTION
1
$   C
    TO CHANGE VOFF,HOFF,MAG,FSCALE,LTABLE,TYPE OF MAPPING ENTER "T" , IF NOT
     ENTER "F"
T
    ENTER VERTICAL AND HORIZONTAL OFFSET FOR PROJECTION DIRECTION (DEGREES)
0,0
    ENTER SCALE FACTOR , SCREEN MAG , YBIAS, XBIAS
     NORMALLY SCREEN MAG = 1.  ,XBIAS = 0.,YBIAS = 0.  THE SCALE FACTOR
     DETERMINES THE TFOV (FSCALE * 90)
1.5,1,0,0
    PICK WHICH TYPE OF MAPPING DESIRED, FOR A TANGENT MAPPING ENTER "1" ,
    FOR AN IDEAL R-THETA MAPPING ENTER "2" , FOR TANTHETA MAPPING WITH
    PRIMARY DISTORTION , ENTER "3" ,FOR SIN THETA MAPPING, ENTER "4"

2
    IF TABLE OUTPUT IS DESIRED TYPE TRUE ; IF NOT FALSE

F
    NO OUTPUT FOR TABLE
     TYPE C TO CONTINUE EXECUTION
1
$   C
   TO CHANGE VOFF,HOFF,MAG,FSCALE,LTABLE,TYPE OF MAPPING ENTER "T" , IF NOT
    ENTER "F"
F
    TO CHANGE SCREEN MAGNIFICATION,ENTER T ,TO STOP ENTER F
F
FORTRAN STOP
$
```

TABLE A-5

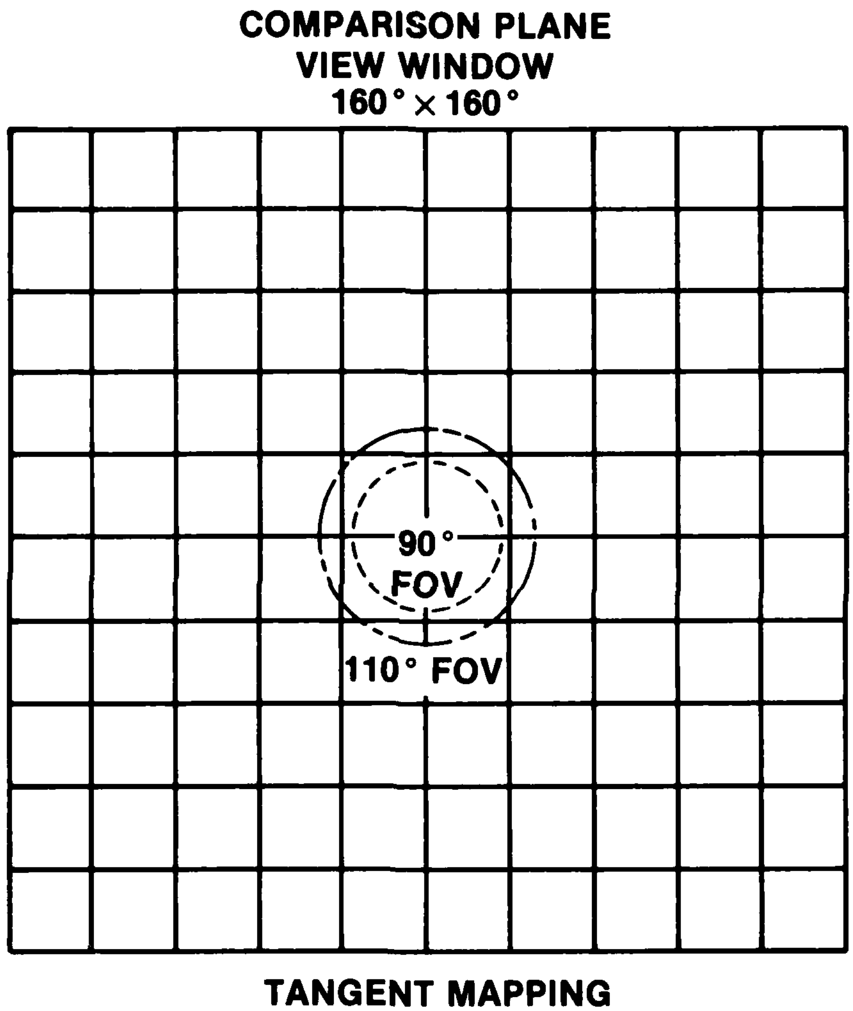


Figure A-5. Tangent mapping (Example 2).

TAN THETA MAPPING COORDINATES

THE VIEWPOINT IS AT :
X = 0.0000 Y = 0.000 Z = 0.000
OBSERVING A LINEAR RASTER PATTERN ON THE SCREEN
FILLING A FIELD OF 160.000 DEGREES VERTICALLY,
AND 160.000 DEGREES HORIZONTALLY
ABOUT A POINT X= 218.000 Y= 0.000
Z= -101.000 DEFINED AS CENTER OF "FOV".

THE PROJECTOR IS AT :
X = -218.0000 Y = 0.000 Z = 101.000
THE PROJECTION DIRECTION IS OFFSET BY V= 0.000 H = 0.000
FROM THE DEFINED FOV CENTER.

THE RADIUS OF THE SPHERICAL SCREEN IS 240.000

X	0.624	0.000	-0.624
Y	0.624	0.838	0.624
XC	5.671	0.000	-5.671
YC	5.671	5.671	5.671
X	0.838	0.000	-0.838
Y	0.000	0.000	0.000
XC	5.671	0.000	-5.671
YC	0.000	0.000	0.000
X	0.624	0.000	-0.624
Y	-0.624	-0.838	-0.624
XC	5.671	0.000	-5.671
YC	-5.671	-5.671	-5.671

DISTORTION PERCENTAGES

1	2	3
18.09%	0.00%	18.09%
4	5	6
0.00%	0.00%	0.00%
7	8	9
18.09%	0.00%	18.09%

TABLE A-6

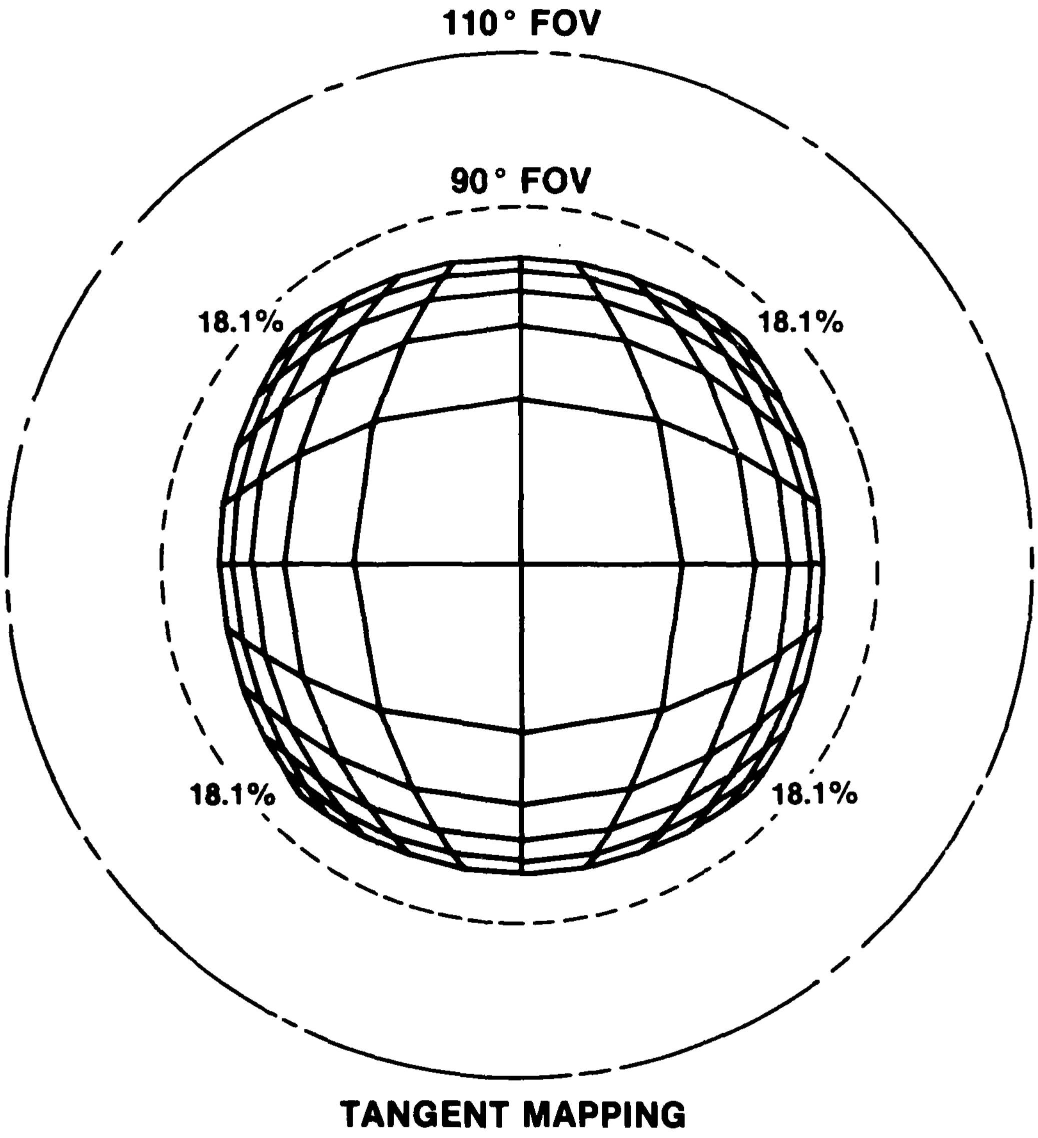


Figure A-6. Tangent mapping (Example 2).

R-THETA MAPPING COORDINATES

THE VIEWPOINT IS AT :
X = 0.0000 Y = 0.000 Z = 0.000
OBSERVING A LINEAR RASTER PATTERN ON THE SCREEN
FILLING A FIELD OF 160.000 DEGREES VERTICALLY,
AND 160,000 DEGREES HORIZONTALLY
ABOUT A POINT X= 218.000 Y= 0.000
Z= -101.000 DEFINED AS CENTER OF "FOV".

THE PROJECTOR IS AT :
X = -218.000 Y= 0.000 Z = 101.000
THE PROJECTION DIRECTION IS OFFSET BY V= 0.000 H = 0.000
FROM THE DEFINED FOV CENTER.

THE RADIUS OF THE SPHERICAL SCREEN IS 240.000

X	0.511	0.000	-0.511
Y	0.511	0.698	0.511
XC	5.671	0.000	-5.671
YC	5.67.	5.671	5.671
X	0.698	0.000	-0.698
Y	0.000	0.000	0.000
XC	5.671	0.000	-5.671
YC	0.000	0.000	0.000
X	0.511	0.000	-0.511
Y	-0.511	-0.698	-0.511
XC	5.671	0.000	-5.671
YC	-5.671	-5.671	-5.671

DISTORTION PERCENTAGES

1	2	3
18.90%	0.00%	18.90%
4	5	6
0.00%	0.00%	0.00%
7	8	9
18.90%	0.00%	18.90%

TABLE A-7

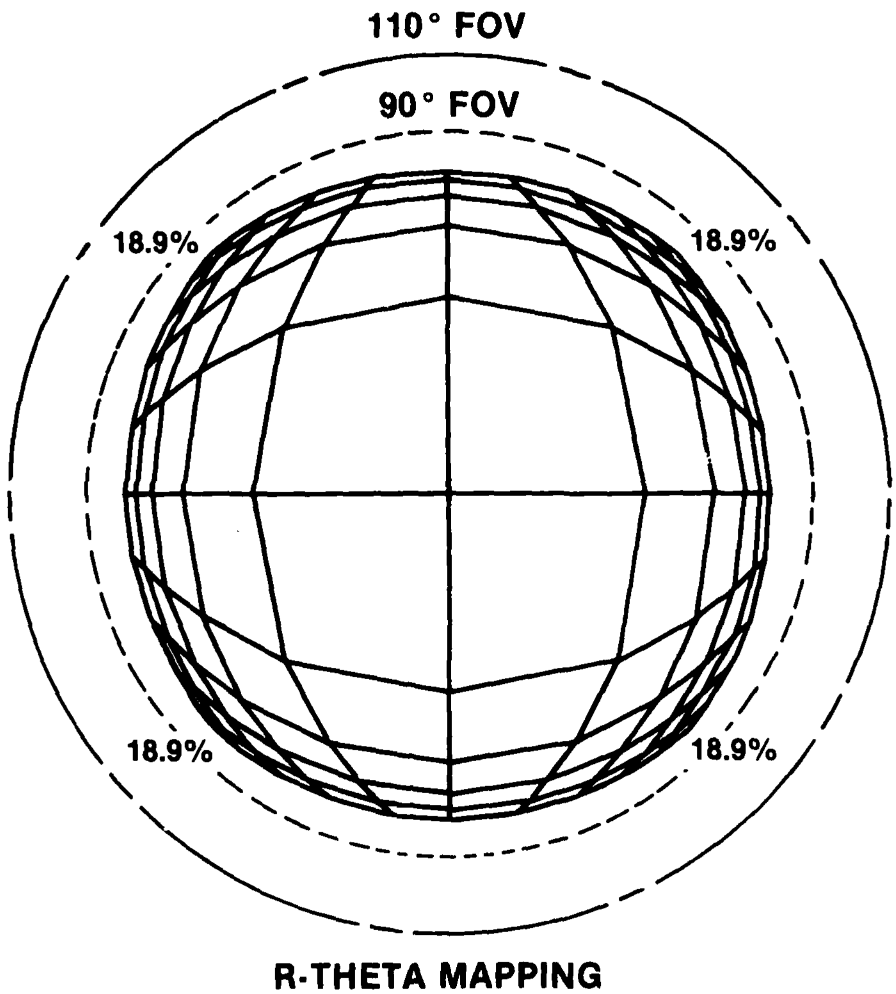


Figure A-7. R-Theta mapping (Example 2).

SIN THETA MAPPING COORDINATES

THE VIEWPOINT IS AT :
X = 0.0000 Y = 0.000 Z = 0.000
OBSERVING A LINEAR RASTER PATTERN ON THE SCREEN
FILLING A FIELD OF 160.000 DEGREES VERTICALLY,
AND 160,000 DEGREES HORIZONTALLY
ABOUT A POINT X= 218.000 Y= 0.000
Z= -101.000 DEFINED AS CENTER OF "FOV".

THE PROJECTOR IS AT :
X = -218.000 Y= 0.000 Z = 101.000
THE PROJECTION DIRECTION IS OFFSET BY V= 0.000 H = 0.000
FROM THE DEFINED FOV CENTER.

THE RADIUS OF THE SPHERICAL SCREEN IS 240.000

X	0.468	0.000	-0.468
Y	0.468	0.642	0.468
XC	5.671	0.000	-5.671
YC	5.671	5.671	5.671
X	0.642	0.000	-0.642
Y	0.000	0.000	0.000
XC	5.671	0.000	-5.671
YC	0.000	0.000	0.000
X	0.468	0.000	-0.468
Y	-0.468	-0.642	-0.468
XC	5.671	0.000	-5.671
YC	-5.671	-5.671	-5.671

DISTORTION PERCENTAGES

1	2	3
19.22%	0.00%	19.22%
4	5	6
0.00%	0.00%	0.00%
7	8	9
19.22%	0.00%	19.22%

TABLE A-8

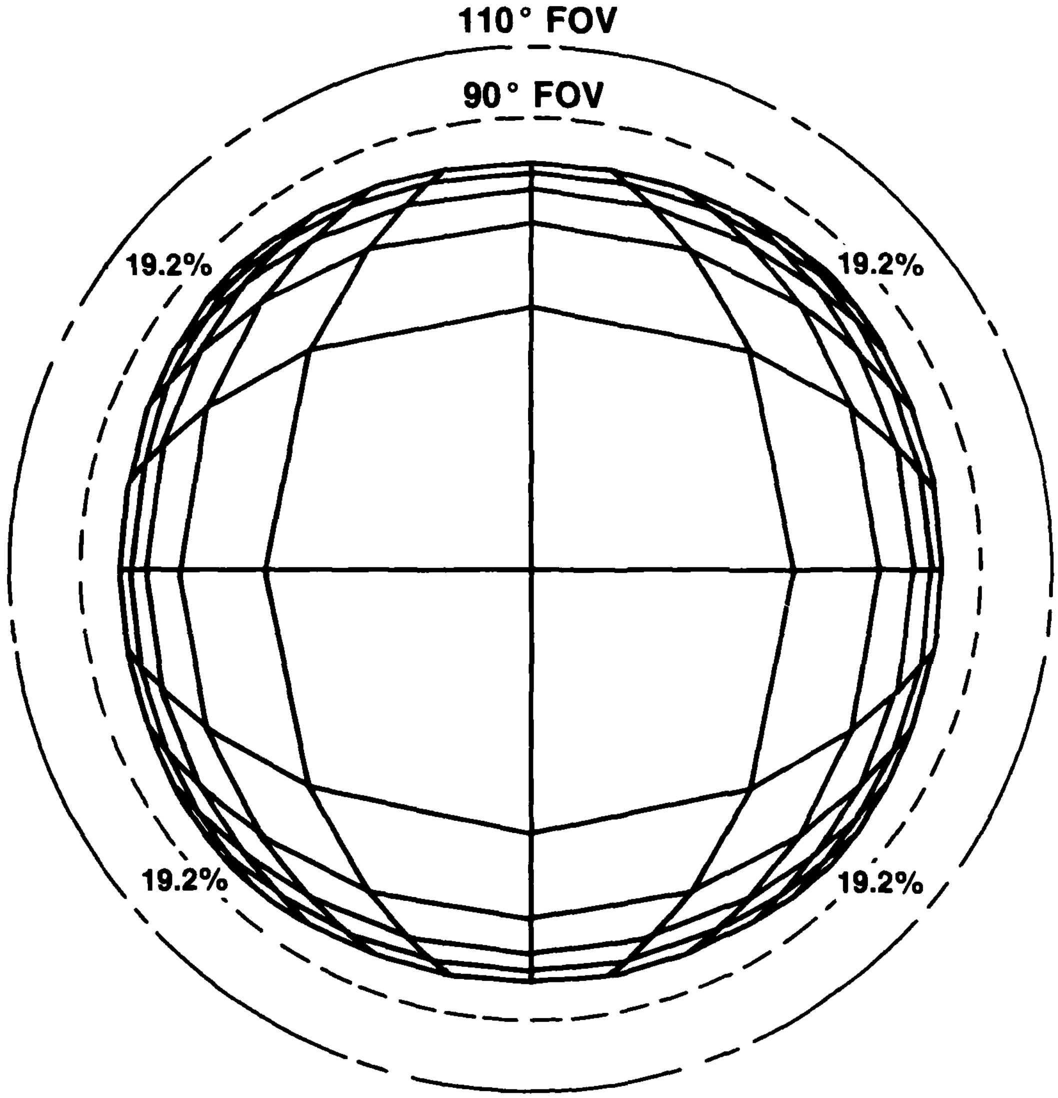


Figure A-8. Sin Theta mapping.

CONVERSION FROM F TAN Θ MAPPINGS TO FΘ, F Sin Θ, AND F TAN Θ WITH PRIMARY DISTORTION MAPPINGS

F Tan Θ mapping

Using spherical angles Φ and Θ to define angles along the X and Y axes of the mapping plane relative to the origin (center of plane) for a point on the plane, the coordinates of the point are found by the equations:

$$X_t = F * \text{Tan } \Phi$$
$$Y_t = F * \text{Tan } \Theta$$

F Θ mapping

A point on the F Tan Θ mapping plane (for F = 1) is located at a radial distance from the origin given by:

$$R_t = [(\text{Tan } \Phi)^2 + (\text{Tan } \Theta)^2]^{1/2}.$$

Considering the difference between the radial distance for a Tan Θ mapping and a Θ mapping for the same point in the field, the Θ mapping radial distance is given by:

$$R_\Theta = R_t * \frac{\alpha}{\tan \alpha},$$

or equivalently,

$$R_\Theta = R_t * CR.$$

Where CR is the conversion ratio constant for a particular point on the plane (Tan Θ), α is the angle from the optical axis.

To find the X and Y coordinates on the Θ mapping plane, expand the conversion equation to:

$$[(X_\Theta)^2 + (Y_\Theta)^2]^{1/2} = [(X_t)^2 + (Y_t)^2]^{1/2} * CR ,$$

and using the property of a scaler multiplication of a vector the resulting coordinates for a F Θ mapping are given by:

$$X_\Theta = X_t * CR ,$$

$$Y_\Theta = Y_t * CR .$$

F sin Θ Mapping

Again considering the radial distance for a point on a Tan Θ mapping, if the radial distance (R_s) for a Sin Θ mapping is desired, then

$$R_s = R_t * \frac{\text{Sin } \alpha}{\text{Tan } \alpha} ,$$

or,

$$[(X_s)^2 + (Y_s)^2]^{1/2} = [(X_t)^2 + (Y_t)^2]^{1/2} \times \frac{\text{Sin } \alpha}{\text{Tan } \alpha} .$$

using the scaler multiplication process again,

$$X_s = X_t * \frac{\text{Sin } \alpha}{\text{Tan } \alpha} ,$$

$$Y_s = Y_t * \frac{\text{Sin } \alpha}{\text{Tan } \alpha} .$$

Tan Θ mapping with Primary Distortion

Primary distortion of a Tan Θ lens is a distortion of the radial position of a point on the mapping plane relative to the square of the radial distance to that point multiplied by a constant factor (DF), i.e.:

$$R_p = R_t + (DF * R_t^2) ,$$

or,

$$R_p = R_t * (1 + (DF * R_t)).$$

Using the general formula for radial distance the above equation expands to:

$$[(X_p)^2 + (Y_p)^2]^{1/2} = [(X_t)^2 + (Y_t)^2]^{1/2} * (1 + DF * R_t)),$$

again scalar multiplication process leads to:

$$X_p = X_t * (1 + (DF * R_t)) ,$$

$$Y_p = Y_t * (1 + (DF + R_t)) ,$$

where X_p and Y_p are the coordinates of the distorted mapping. Obviously, letting DF = 0 will give a Tan Θ mapping, with a negative DF value giving barrel distortion and a positive DF value giving pincushion distortion.

The figures below illustrate the difference between the mappings through a lens of a rectangular object for the four general mappings described above. Notice that for the proper choice of *DF*, an *F* Θ *mapping* or *F Sin* Θ *mapping* can be approximated if the field angles are not too large.

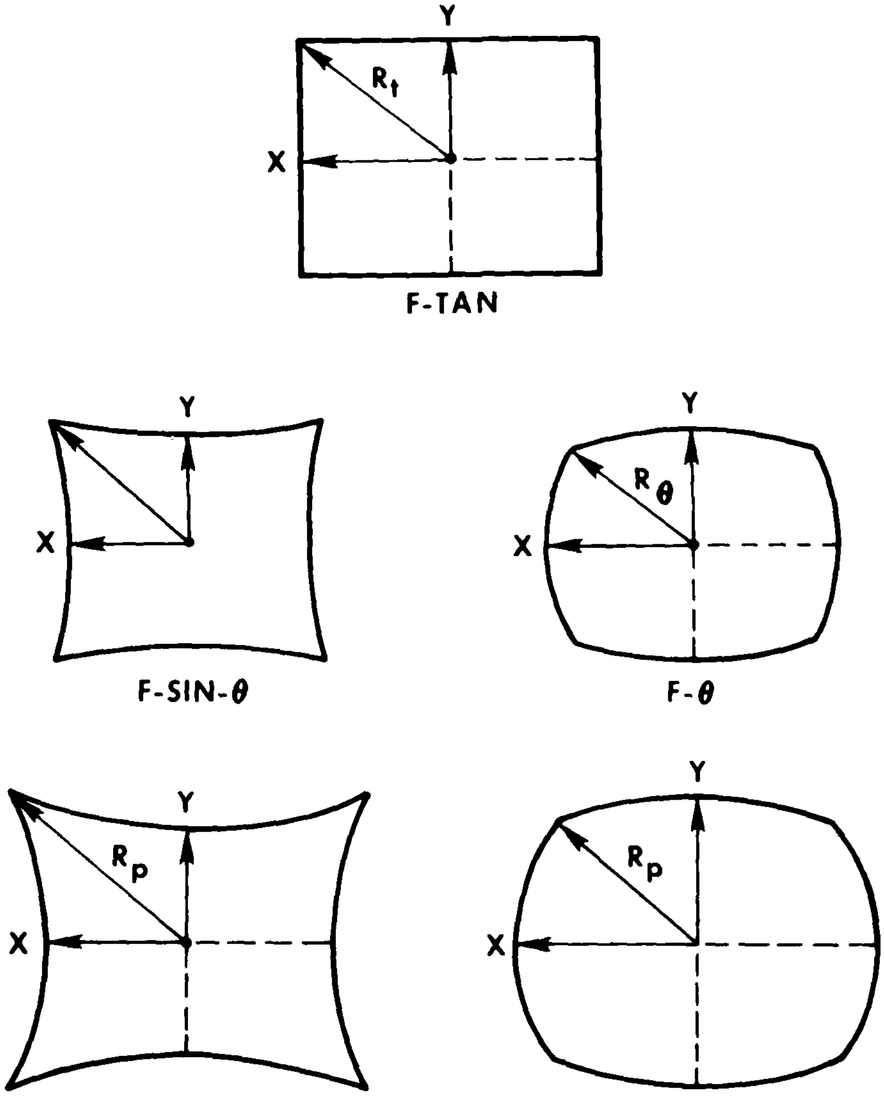
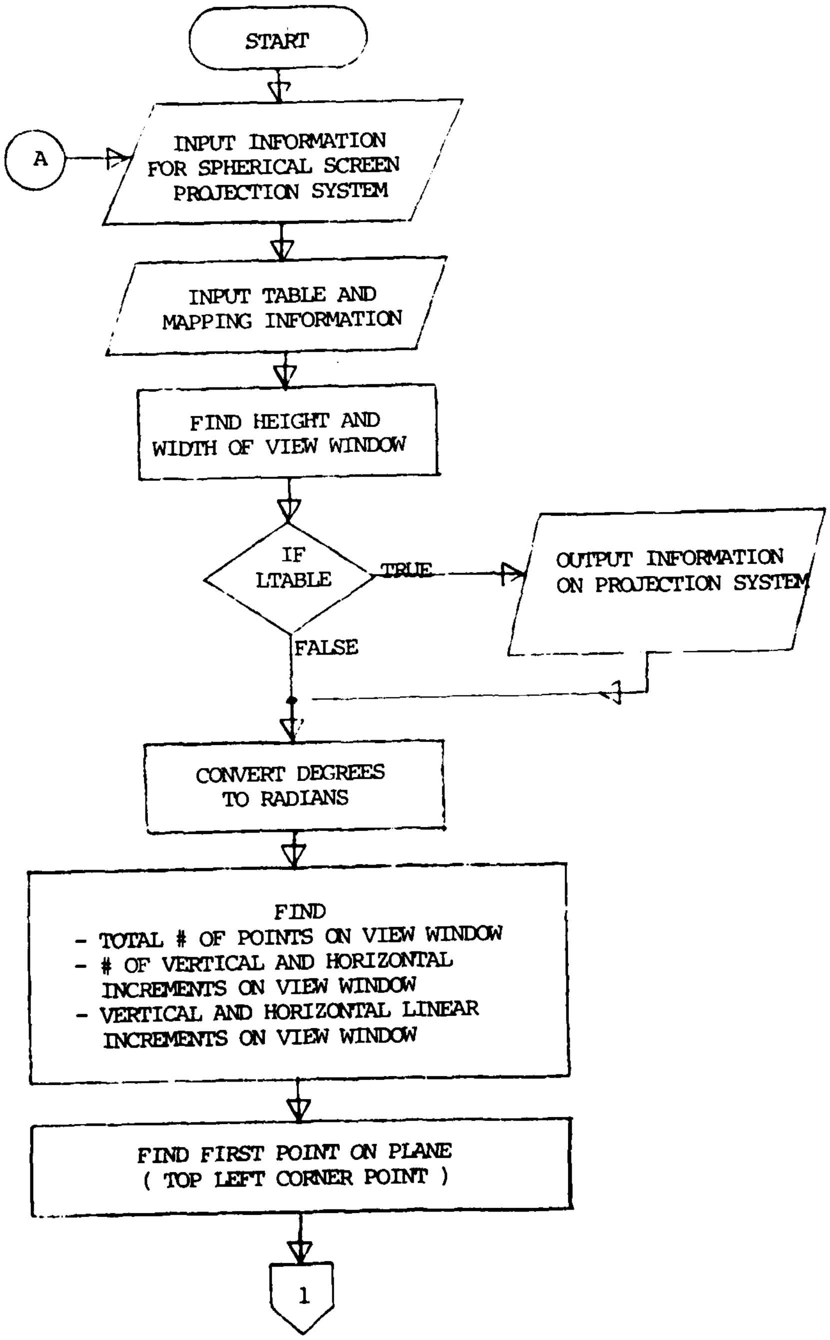
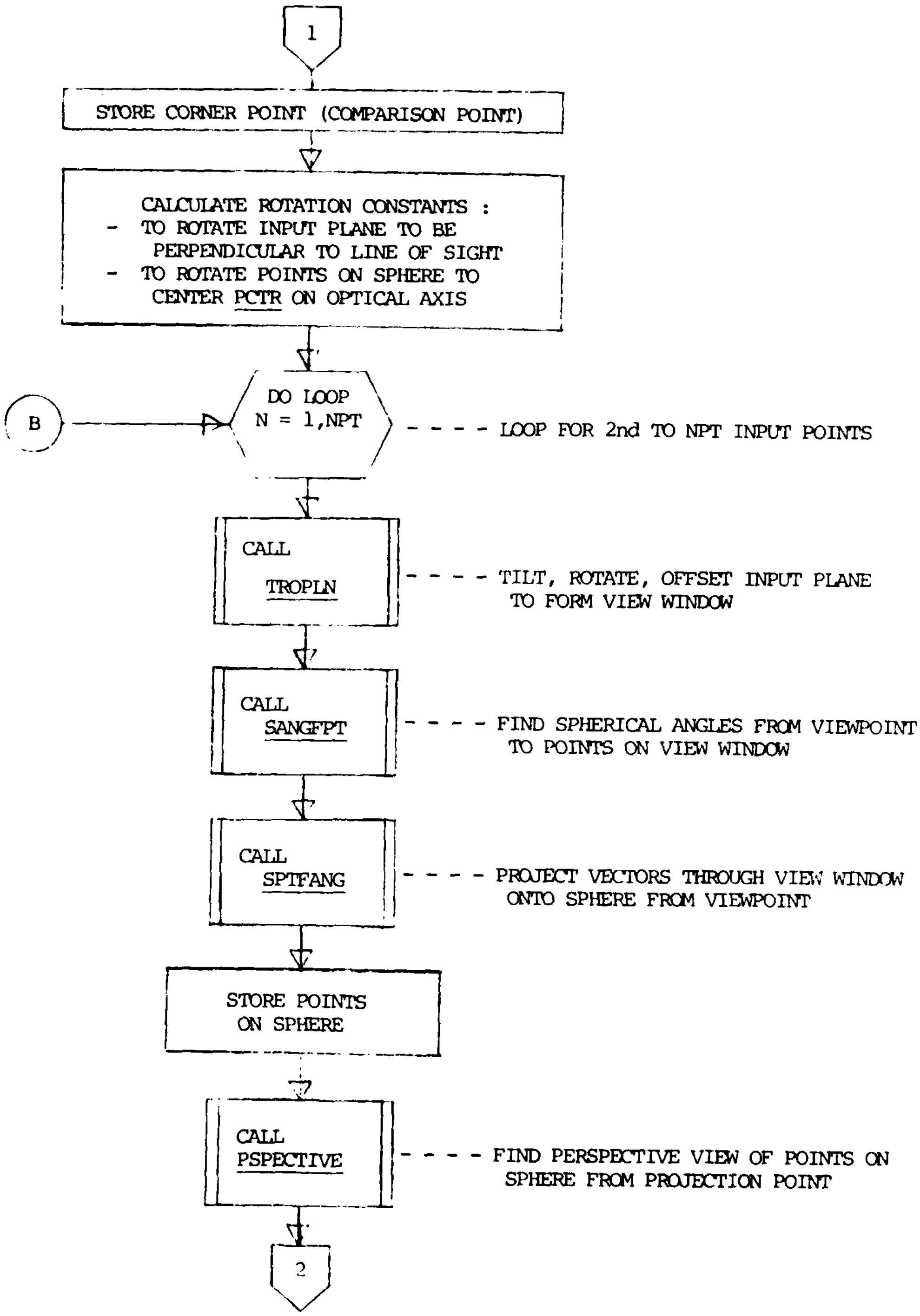


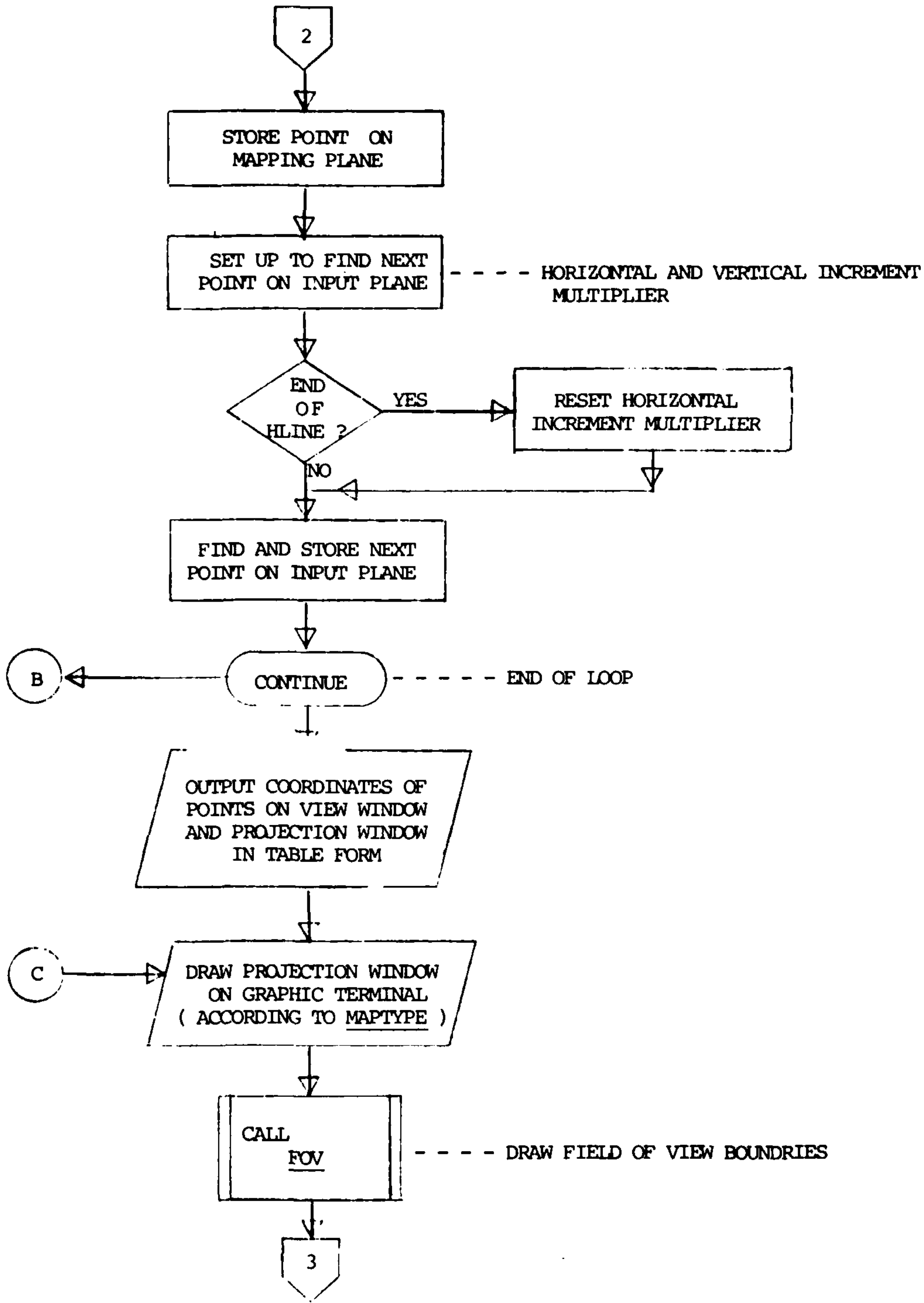
Figure B-1. Relative Distortions of a Rectangular Object by Various Lens Mapping Functions.

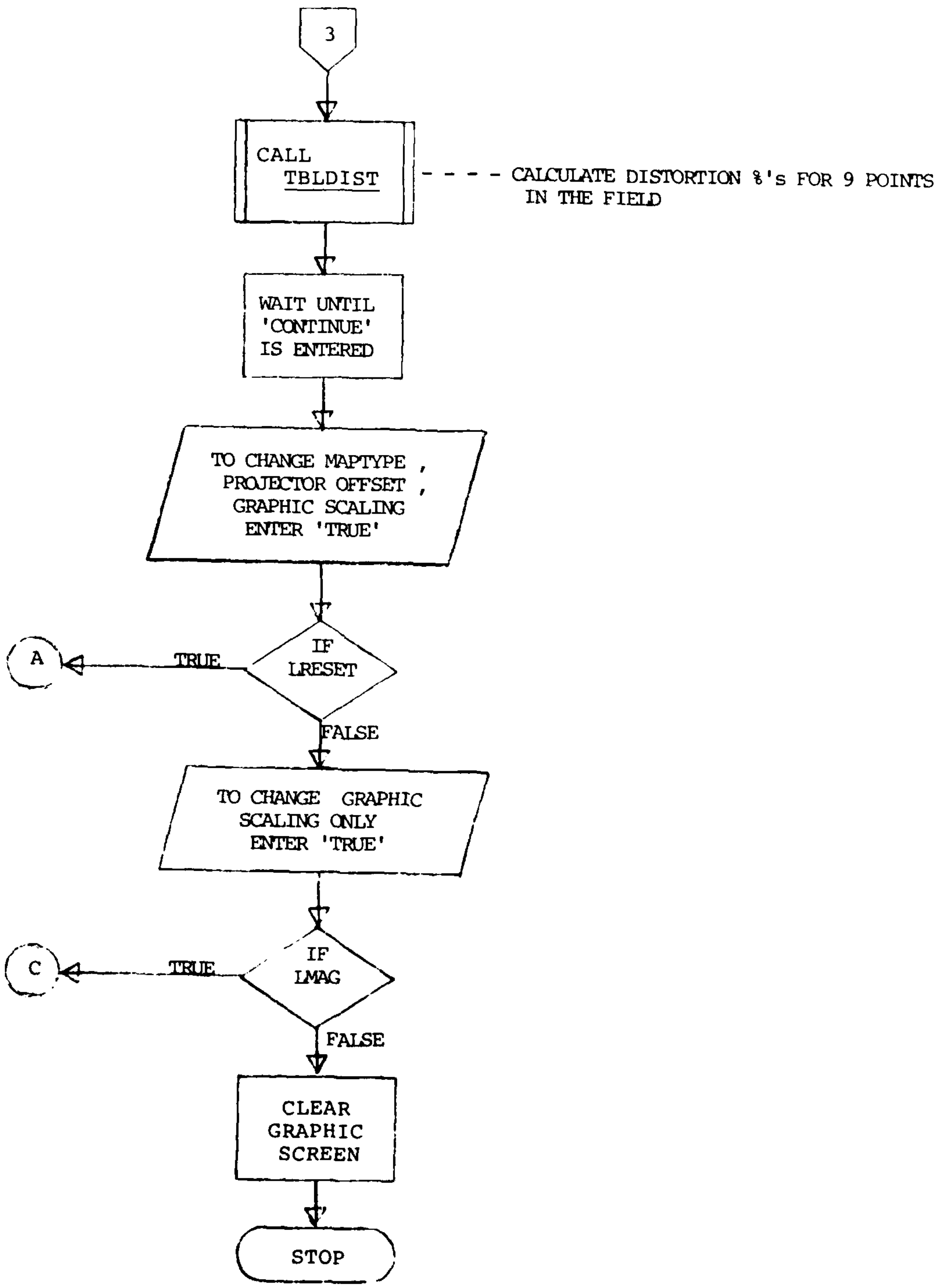
PROGRAM FLOWCHARTS AND CODING

MAPTAG

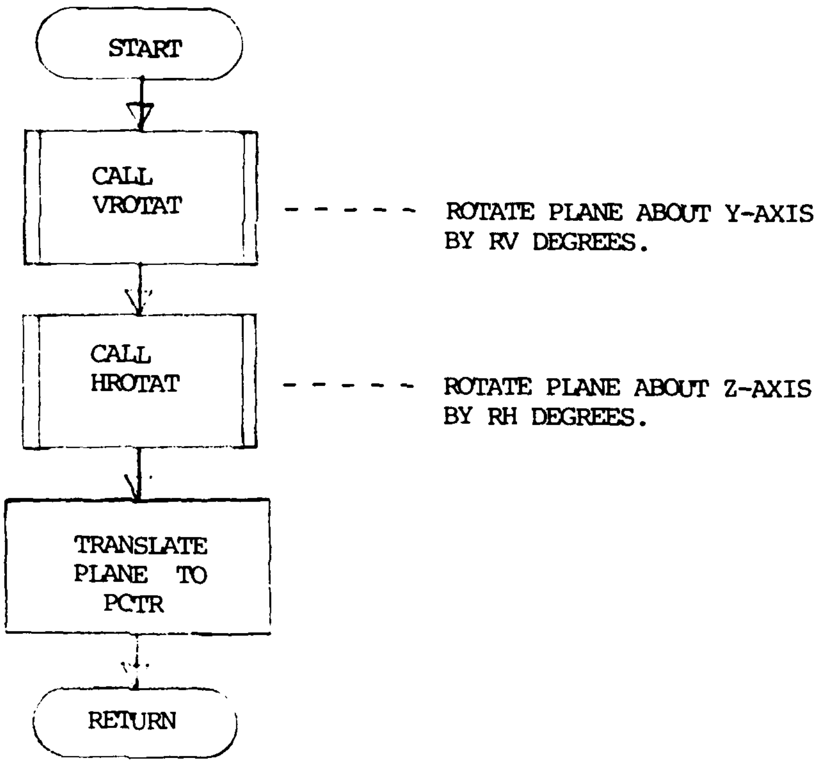

START
A
INPUT INFORMATION FOR SPHERICAL SCREEN PROJECTION SYSTEM
INPUT TABLE AND MAPPING INFORMATION
FIND HEIGHT AND WIDTH OF VIEW WINDOW
IF LTABLE
TRUE
OUTPUT INFORMATION ON PROJECTION SYSTEM
FALSE
CONVERT DEGREES TO RADIANS
FIND
- TOTAL # OF POINTS ON VIEW WINDOW
- # OF VERTICAL AND HORIZONTAL INCREMENTS ON VIEW WINDOW
- VERTICAL AND HORIZONTAL LINEAR INCREMENTS ON VIEW WINDOW
FIND FIRST POINT ON PLANE (TOP LEFT CORNER POINT)
1


1
STORE CORNER POINT (COMPARISON POINT)
CALCULATE ROTATION CONSTANTS :
- TO ROTATE INPUT PLANE TO BE PERPENDICULAR TO LINE OF SIGHT
- TO ROTATE POINTS ON SPHERE TO CENTER PCTR ON OPTICAL AXIS
B
DO LOOP N = 1,NPT
LOOP FOR 2nd TO NPT INPUT POINTS
CALL TROPLN
TILT, ROTATE, OFFSET INPUT PLANE TO FORM VIEW WINDOW
CALL SANGFPT
FIND SPHERICAL ANGLES FROM VIEWPOINT TO POINTS ON VIEW WINDOW
CALL SPTFANG
PROJECT VECTORS THROUGH VIEW WINDOW ONTO SPHERE FROM VIEWPOINT
STORE POINTS ON SPHERE
CALL PSPECTIVE
FIND PERSPECTIVE VIEW OF POINTS ON SPHERE FROM PROJECTION POINT
2


2
STORE POINT ON MAPPING PLANE
SET UP TO FIND NEXT POINT ON INPUT PLANE
HORIZONTAL AND VERTICAL INCREMENT MULTIPLIER
END OF HLINE ?
YES
RESET HORIZONTAL INCREMENT MULTIPLIER
NO
FIND AND STORE NEXT POINT ON INPUT PLANE
B
CONTINUE
END OF LOOP
OUTPUT COORDINATES OF POINTS ON VIEW WINDOW AND PROJECTION WINDOW IN TABLE FORM
C
DRAW PROJECTION WINDOW ON GRAPHIC TERMINAL (ACCORDING TO MAPTYPE)
CALL FOV
DRAW FIELD OF VIEW BOUNDRIES
3


3
CALL
TBLDIST
CALCULATE DISTORTION %'s FOR 9 POINTS
IN THE FIELD
WAIT UNTIL
'CONTINUE'
IS ENTERED
TO CHANGE MAPTYPE ,
PROJECTOR OFFSET ,
GRAPHIC SCALING
ENTER 'TRUE'
A
TRUE
IF
LRESET
FALSE
TO CHANGE GRAPHIC
SCALING ONLY
ENTER 'TRUE'
C
TRUE
IF
LMAG
FALSE
CLEAR
GRAPHIC
SCREEN
STOP

SUBROUTINE TROPLN

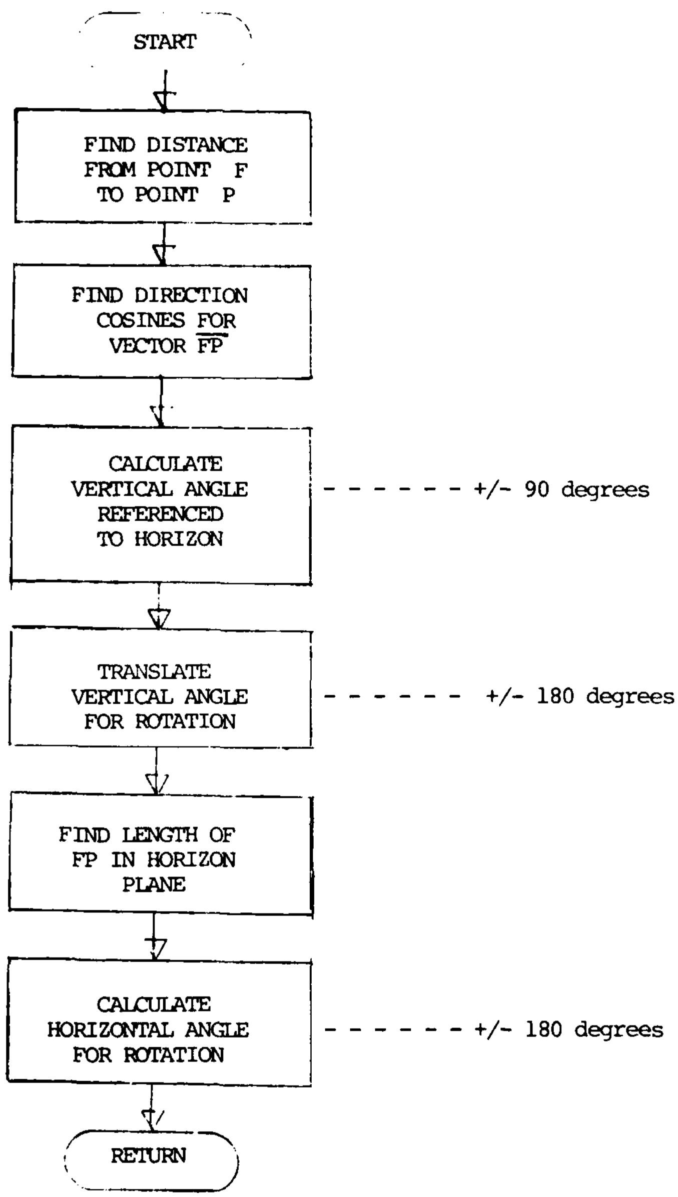


INPUT: POINT ON PLANE,P(PX,PY,PZ), VERTICAL ROTATION ANGLE (RV), HORIZONTAL ROTATION ANGLE (RH), PLANE CENTER PCTR(PXC,PYC,PZC), ORIGIN OF PLANE (XO,YO,ZO).

OUTPUT: POINT ON PLANE P(PX,PY,PZ) - (TILTED,ROTATED AND OFFSET)

```
              22-JAN-1981  15:45:10   VAX 11 FORTRAN IV-PLUS  V1.2-13     Page 1
                                      SUBDIST.FOR.1
              C
              C
              C        **********
              C        *        *
              C        * TROPLN *
              C        *        *
              C        **********
              C
              C    THIS SUBROUTINE COVERTS POINTS ON A Y-Z PLANE CENTERED AT
              C     AN ORIGIN TO POINTS ON A PLANE THAT IS TILTED ABOUT THE Y-A
              C     BY RV DEGREES AND THEN ROTATED RH DEGREES ABOUT THE Z-AX
              C     THE PLANE IS THEN TRANSLATED FROM THE ORIGIN TO (PXC,PYC,
              C     THE PLANE PRODUCED WILL BE TANGENT TO THE PROJECTION
              C     DIRECTION IF CTHE ROTATION ANGLES ARE THE NEGATIVE OF THE
              C     ANGLES FROM PROJECTOR TO (PXC,PYC,PZC) OF THE SPHERE CENTERE
              C     COORDINATE SYSTEM.
              C
              C
0001                 SUBROUTINE TROPLN (RV,RH,PXC,PYC,PZC,XO,YO,ZO,PX,PY,PZ)
0002                 IMPLICIT DOUBLE PRECISION (D,F,P,P,X,Y,Z)
              C
              C
              C    TRANSLATE PLANE TO ORIGIN AT (XO,YO,ZO)
              C
0003                 PX = PX - XO
0004                 PY = PY - YO
0005                 PZ = PZ - ZO
              C
              C
              C
              C    ROTATE PLANE ABOUT Y-AXIS BY RV DEGREES
              C
0006                 CALL VROTAT(RV,PX,PY,PZ)
              C
              C    ROTATE ABOUT Z-AXIS BY RH DEGREES
              C
0007                 CALL HROTAT(RH,PX,PY,PZ)
              C
              C
              C    TRANSLATE PLANE FROM PROJECTION POINT TO POSITION CENTERED AT
              C     PXC,PYC,PZC.
              C
0008                 PX = PX + PXC - XO
0009                 PY = PY + PYC - YO
0010                 PZ = PZ + PZC - ZO
              C
              C
0011                 RETURN
0012                 END
```

SUBROUTINE SANGFPT



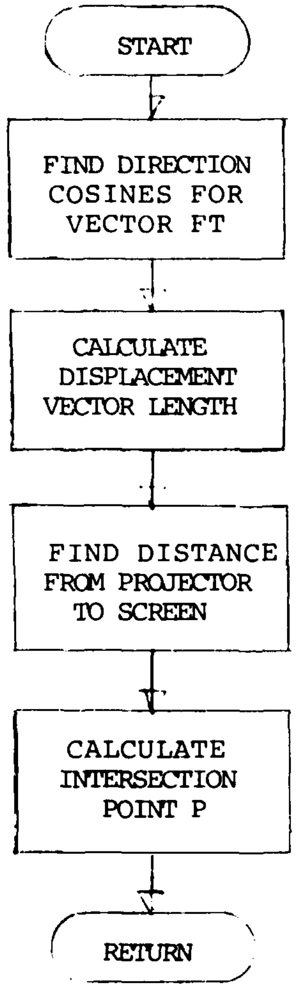
INPUT : DEGREES TO RADIAN FACTOR (PI), POINT F(FX,FY,FZ), POINT P(PX,PY,PZ).

OUTPUT: 'VANG' (VERTICAL +/- 90 DEGREES FROM HORIZON) , 'TILT' (-'VANG'), 'VANGR' (VERTICAL +/- 180 DEGREES), 'HANGR' (HORIZONTAL +/- 180 DEGREES), 'DIST' (DISTANCE $\overline{FP}$)

```
C
C
C
C         ************
C         *          *
C         *  SANGFPT *
C         *          *
C         ************
C
C    THIS SUBROUTINE FINDS SPHERICAL ANGLES TO POINT PX,PY,PZ
C    FROM POINT FX,FY,FZ. ANGLES ARE EXPRESSED IN RADIANS. ALSO
C    THE DISTANCE FROM F TO P IS RETURNED IN THE SAME UNITS AS
C    POINT LOCATIONS ARE GIVEN.
C    THREE ANGULAR SIGN CONVENTIONS ARE USED IN THIS PROGRAM
C     1. POSITIVE ABOVE HORIZON , NEGATIVE BELOW HORIZON
C        CONVENTION . VERTICAL ANGLES ONLY (+/- 90 DEG.)
C        VALUES RETURNED AS "VANG".
C     2. POSITIVE FOR COUNTER-CLOCKWISE ROTATION , NEGATIVE
C        FOR CLOCKWISE ROTATION AS VIEWED FROM POSITION ON
C        A POSITIVE AXIS LOOKING TOWARDS PLANE DEFINED BY
C        REMAINING AXES. VERTICAL AND HORIZONTAL ANGLES;
C        VALUES RETURNED AS 'VANGR' AND 'HANGR'
C     3. VALUE FOR TILTING OF INPUT PLANE BY TROPLN SUBROUTINE
C        THIS ANGLE IS NEGATIVE OF VANG.
C
     SUBROUTINE SANGFPT(PI,PX,PY,PZ,FX,FY,FZ,VANG,HANGR,DIST,VANGR,
     TILT 1)
C
     IMPLICIT DOUBLE PRECISION (A,B,C,D,F,H,P,T,V)
C
C    FIND DISTANCE FROM POINT F TO POINT P
        A = PX - FX
        B = PY - FY
        C = PZ - FZ
     DIST = DSQRT(A * A + B * B + C * C )
C
C    FIND DIRECTION COSINES TO P FROM F
C
       DYC = B / DIST
       DZC = C / DIST
C
C    FIND SPHERICAL ANGLES TO P FROM F
C
       VANG = DASIN(DZC)
C    STORE ABSOLUTE VERTICAL ANGLE (+/- 180 DEG.)
       IF (A .LE. 0. .AND. C .GT. 0.)THEN
        VANGR = - 180.*PI + VANG
       ELSE
        IF ( .LT. 0. .AND. C .LT. 0.) THEN
         VANGR = 180.*PI + VANG
       ELSE
         VANGR = - VANG
         ENDIF
       ENDIF
C
C
```

```
C     STORE TITLE VALUE (+/- 90 DEG.)
C
      TILT = - VANG
C
C
C     FIND PROJECTION OF VECTOR ONTO X-Y PLANE
C
      CS = DSQRT(1.0 - DZC*DZC)
C
        IF (CS .EQ. 0.0) THEN
        HANGR = 0.0
        ELSE
       ARGH = DYC / CS
       IF ( ARGH .GT. 1.0) ARGH = 1.0
       IF ( ARGH .LT.-1.0) ARGH =-1.0
D      WRITE(2,*),'ARGH =' CS =',CS
      HANGR = DASIN(ARGH)
        ENDIF
C
C     CONVERT HORIZONTAL ANGLES TO +/- 180 DEGREE CONVENTION
C
        IF ( B .LE. 0. .AND. A .LT. 0. ) HANGR = -180. * PI - HANGR
        IF ( B .GT. 0. .AND. A .LT. 0. ) HANGR =  180. * PI - HANGR
C
        RETURN
        END
```

SUBROUTINE SPTFANG



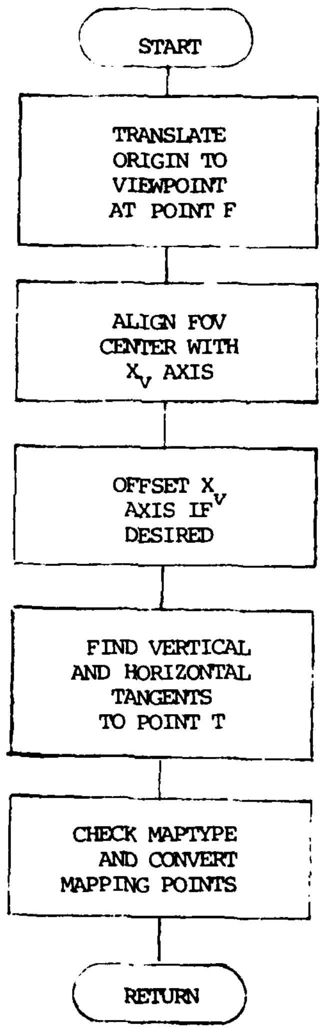
INPUT: RADIUS (R), VERTICAL ANGLE (VANG), HORIZONTAL ANGLE (HANG), PROJECTION POINT F(FX,FY,FZ).

OUTPUT: INTERSECTION POINT ON SCREEN T(TX,TY,TZ).

```
                30-JAN-1981  12:12:13     VAX-11 FORTRAN IV-PLUS V1.2-13    Page 3
                                          TESTSUB.FOR.1

                C
                C
                C     ***********
                C     *         *
                C     * SPTFANG *
                C     *         *
                C     ***********
                C
                C
                C     THIS SUBROUTINE FINDS THE POINT OF INTERSECTION OF A VECTOR
                C      PROJECTED FROM A POINT ( FX,FY,FZ ) AT SPHERICAL ANGLES OF 'VANG'
                C      AND 'HANG' ONTO THE SURFACE OF A SPHERE WITH THE CENTER DEFINED
                C      AS THE ORIGIN OF THE 3-D SYSTEM. THE COORDINATE SYSTEM OF THE
                C      PROJECTION POINT IS PARALLEL TO THE SCREEN COORDINATE SYSTEM.
                C      THE POINT RETURNED IS GIVEN BY ( PX,PY,PZ ) AND IS ON THE
                C      SURFACE OF THE DESCRIBED SPHERE OF RADIUS (R)
                C
0001                        SUBROUTINE SPTFANG (R,VANG,HANG,FX,FY,FZ,TX,TY,TZ)
0002                        IMPLICIT DOUBLE PRECISION (D,F,H,R,T,V)
                C
                C     FIND DIRECTION COSINES FROM F TO T
                C
0003                         DCV = DCOS(VANG)
0004                        DZP = DSIN(VANG)
0005                        DYP = DCV * DSIN(HANG)
0006                        DXP = DCV * DCOS(HANG)
                C
                C     FIND LENGTH OF DISPLACEMENT VECTOR DUE TO PROJECTOR OFF CENTER
                C     OF SPHERE
                C
0007                        DVMS = FX * DXP + FY * DYP + FZ * DZP
                C
                C     FIND DISTANCE FROM PROJECTION POINT TO POINT ON SCREEN
                C
0008                        DVAL = DABS (DVMS*DVMS + R*R - FX*FY -FY*FY - FZ*FZ)
                C
0009                        DIST = - DVMS + DSQRT( DVAL )
                C
                C     FIND COORDINATES OF POINT
                C
0010                        TX = FX + DIST * DXP
0011                        TY = FY + DIST * DYP
0012                        TZ = FZ + DIST * DZP
                C
0013                        RETURN
0014                        END
```

SUBROUTINE PSPECTIVE



INPUT : VIEWPOINT F(FX,FY,FZ) , POINT TO BE VIEWED T(TX,TY,TZ), ANGLES TO ALIGN X_V AXIS TO FOV CENTER (VOFF,HOFF), ANGLES TO OFFSET X_V AXIS (VOFFP,HOFFP), MAPTYPE, PRIMARY DISTORTION FACTOR (DFACTOR).

OFFSET : COORDINATES OF POINT ON VIEWPLANE (XOUT,YOUT).

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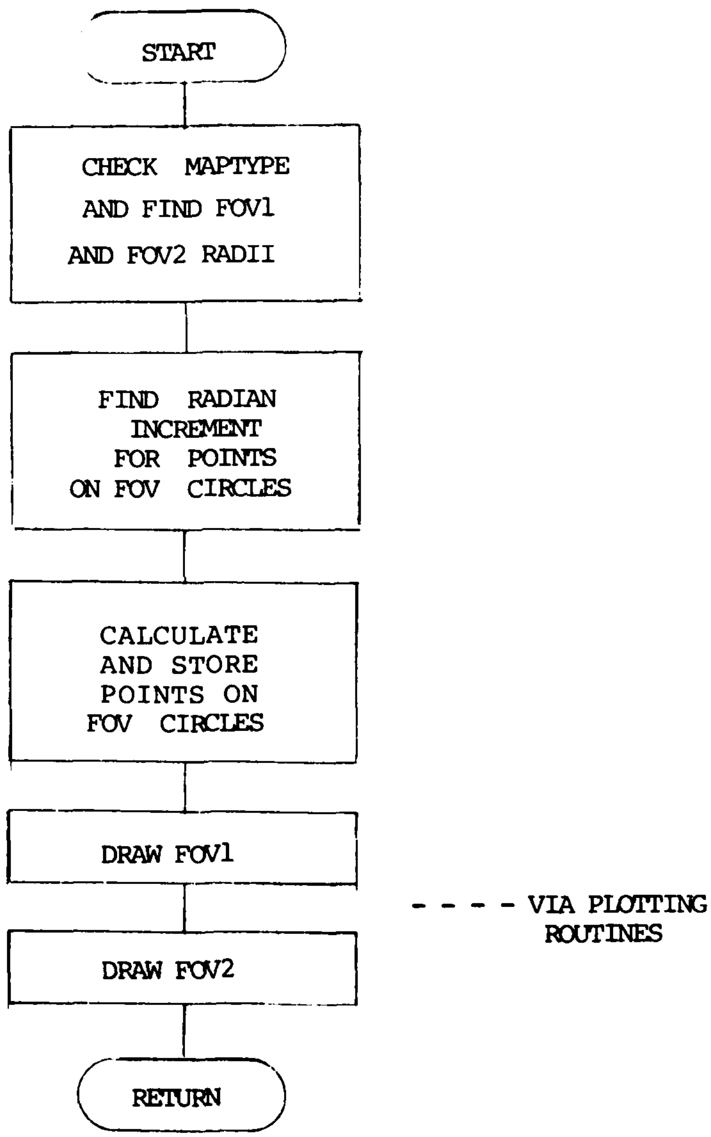
```
      C
      C
      C
      C
      C
      C
      C     **************************
      C     *                        *
      C     *       PERSPECTIVE      *
      C     *                        *
      C     **************************
      C
      C     THIS SUBROUTINE IS USED TO FIND THE PERSPECTIVE MAPPING OF
      C     POINTS IN 3-D SPACE WHERE THE COORDINATE SYSTEM IS DESCRIBED
      C     AS: X IS POSITIVE FORWARD, Y IS POSITIVE TO THE RIGHT, AND
      C     Z IS POSITIVE UPWARDS ( RIGHT-HAND SYSTEM ).
      C     THE PERSPECTIVE IS FOUND FROM A POINT (FX,FY,FZ) WITH THE
      C     VIEWING VECTOR OFFSET FROM OH,OV DEGREES BY -VOFF DEGREES
      C     AND -HOFF DEGREES IN AN ANGULAR SYSTEM THAT DEFINES THE
      C     DIRECTION OF POSTIVE ROTATION AS COUNTER-CLOCKWISE ROTATION
      C     OF TWO AXES WHEN VIEWED FROM THE REMAINING AXIS.
      C
      C                             Z
      C                             '
      C                             '
      C                             '
      C                             '
      C         OV,OH      X<---------*> EYE
      C                              /
      C                             /
      C                            /
      C                           /
      C                          \/  OV,90H
      C                          Y
      C
      C     THE POINT TO BE MAPPED IS (TX,TY,TZ) ACCORDING TO MAPTYPE
      C     (1-TAN-THETA,2-THETA,3-TAN-THETA W/ DFACTOR,4-SIN-THETA)
      C
      C     VOFFP AND HOFFP ALLOW FURTHER OFFSETTING OF THE VIEWING AXIS.
      C     XOUT AND YOUT ARE THE COORDINATES FOR PLANAR PERPECTIVE VIEW.
      C
      C
0001        SUBROUTINE PSPECTIVE(FX,FY,FZ,TX,TY,TZ,VOFF,HOFF,VOFFP,HOFFP,
           1MAPTYPE,DFACTOR,XOUT,YOUT)
      C
      C
0002        IMPLICIT DOUBLE PRECISION (A-H,O-Z)
      C
      C     TRANSLATE ORIGIN TO VIEWPOINT POSITION (FX,FY,FZ)
0003              TX = TX - FX
0004              TY = TY - FY
0005              TZ = TZ - FZ
      C
      C     POINT Xv AXIS TOWARD FOV CENTER AND FIND NEW COORDINATES
      C
0006              CALL HROTAT (HOFF,TX,TY,TZ)
0007            CALL VROTAT (VOFF,TX,TY,TZ)
      C
      C     OFFSET VIEWING AXIS IF HOFFP AND VOFFP ARE NOT ZERO
      C
0008            IF(VOFFP .NE. 0.0) CALL VROTAT (VOFFP,TX,TY,TZ)
0009            IF(HOFFP .NE. 0.0) CALL HROTAT (HOFFP,TX,TY,TZ)
      C
```

```
C     FIND TANGENTS OF ANGLES TO POINTS
C
C
           IF (TX .EQ. 0.) THEN
C          SET
           XOUT = 0.
           YOUT = 0.
           RETURN
        ENDIF
C
C
C
           TTHETA = TZ / TX
           TANPHI = TY / TX
C
C
C
CMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMM
C111111111111111111111111111111111111111111111111111111111111111111
          TF( MAPTYPE .EQ. 1) THEN
C     FIND TANGENT PROJECTIONS ONTO PLANE
C
           XOUT =  TANPHI
           YOUT =  TTHETA
C
           RETURN
C
           ENDIF
C111111111111111111111111111111111111111111111111111111111111111111
C
C
C     ELSE FIND TANGENT RADIAL DISTANCE (TRDIST) AND CHECK FOR MAPTYPE
C
           TRDIST = DSQRT(TANPHI * TANPHI + TTHETA * TTHETA)
C
           IF(TRDIST .EQ. 0.) THEN
            XOUT = 0.
            YOUT = 0.
C
             RETURN
C
C           ENDIF
C
C
C
C222222222222222222222222222222222222222222222222222222222222222222
C
            IF (MAPTYPE .EQ. 2) THEN
C     FIND THETA PROJECTIONS ONTO PLANE
            THETAN = DATAN(TRDIST)/TRDIST
C
            XOUT = TANPHI * THETAN
            YOUT = TTHETA * THETAN
C
            RETURN
           ENDIF
C
C222222222222222222222222222222222222222222222222222222222222222222
C
C
C333333333333333333333333333333333333333333333333333333333333333333
C
C
            IF ( MAPTYPE .EQ. 3)THEN
```

```
C     FIND TAN-THETA PROJECTION WITH PRIMARY DISTORTION
C
              FIRST = TANPHI*TANPHI + TTHETA*TTHETA
              DTERM = 1 + DFACTOR * FIRST
C
              XOUT = TANPHI * DTERM
              YOUT - TTHETA * DETERM
C
          RETURN
         ENDIF
C
C3333333333333333333333333333333333333333333333333333333333333333
C
C
C4444444444444444444444444444444444444444444444444444444444444444
C
           IF (MAPTYPE .EQ. 4) THEN
C     FIND SIN THETA PROJECTIONS ONTO PLANE
C
             SINN = DSIN(DATAN(TRDIST))/TRDIST
C
             XOUT = TANPHI * SINN
             YOUT = TTHETA * SINN
C
             RETURN
C
            ENDIF
C4444444444444444444444444444444444444444444444444444444444444444
C
CMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMM
C
             RETURN
             END
```

SUBROUTINE FOV



INPUT : FIELD OF VIEW #1 (FOV1), FIELD OF VIEW #2 (FOV2), NUMBER OF POINTS ON FOV's (NPT), LINE TYPE FOR FOV1 (L1), LINE TYPE FOR FOV2 (L2), DEGREES TO RADIANS FACTOR (CONVR), MAPTYPE (MAP), PRIMARY DISTORTION FACTOR (DFACTOR).

OUTPUT : TO GRAPHIC TERMINAL ONLY - CIRCLES INDICATING FOV1 AND FOV2.

```
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                                   TESTSUB.FOR.1
          C
          C
          C
          C
          C     ***********
          C     *         *
          C     *   FOV   *
          C     *         *
          C     ***********
          C
          C
          C     THIS SUBROUTINE GENERATES POINTS FOR FOV BOUNDARIES
          C      CORRESPONDING TO FOV1 AND FOV2, FOR TANGENT MAPPING
          C      MAP = 1, FOR IDEAL R-THETA MAPPING MAP = 2, FOR R-THETA
          C      MAPPING WITH PRIMARY DISTORTION MAP = 3, FOR SIN THETA
          C      MAPPING MAP = 4.
          C
          C
          C      A MAXIMUM OF 75 POINTS IS ALLOWED
          C
          C     THIS ROUTINE IS CALLED AFTER THE GRAPHIC TERMINAL IS
          C      INITIATED BY A CALL TO CPLOT (IE. SCALING IS SET)
          C
          C
0001             SUBROUTINE FOV (FOV1,FOV2,NPT,L1,L2,CONVR,MAP,DFACTOR)
          C
0002             DIMENSION X1(75),X2(75),Y1(75),Y2(75)
          C
          C     FIND RADII OF BOUNDARY CIRCLES
          C
0003             IF ( MAP .EQ. 1 )THEN
0004             R1 = TAN( FOV1*0.5 * CONVR )
0005             R2 - TAN( FOV2*0.5 * CONVR )
0006             ENDIF
          C
0007             IF ( MAP .EQ. L )THEN
          C     FIND RADII FOR R-THETA BOUNDARIES
0008             R1 = FOV1*0.5 * CONVR
0009             R2 - FOV2*0.5 * CONVR
0010            ENDIF
          C
0011             IF ( MAP .EQ. 3 )THEN
          C     FIND RADII FOR TANTHETA W/PRIMARY DISTORTION BOUNDARIES
0012              R1 = TAN( FOV1*0.5 * CONVR )
0013              R2 = TAN( FOV2*0.5 * CONVR )
0014             R1 = RT1 * ( 1 + DFACTOR * RT1*RT1 )
0015             R2 = RT2 * ( 1 + DFACTOR * RT2*RT2 )
0016            ENDIF
          C
0017              IF (MAP .EQ. 4) THEN
0018                R1 = SIN( FOV1 * .5 * CONVR)
```
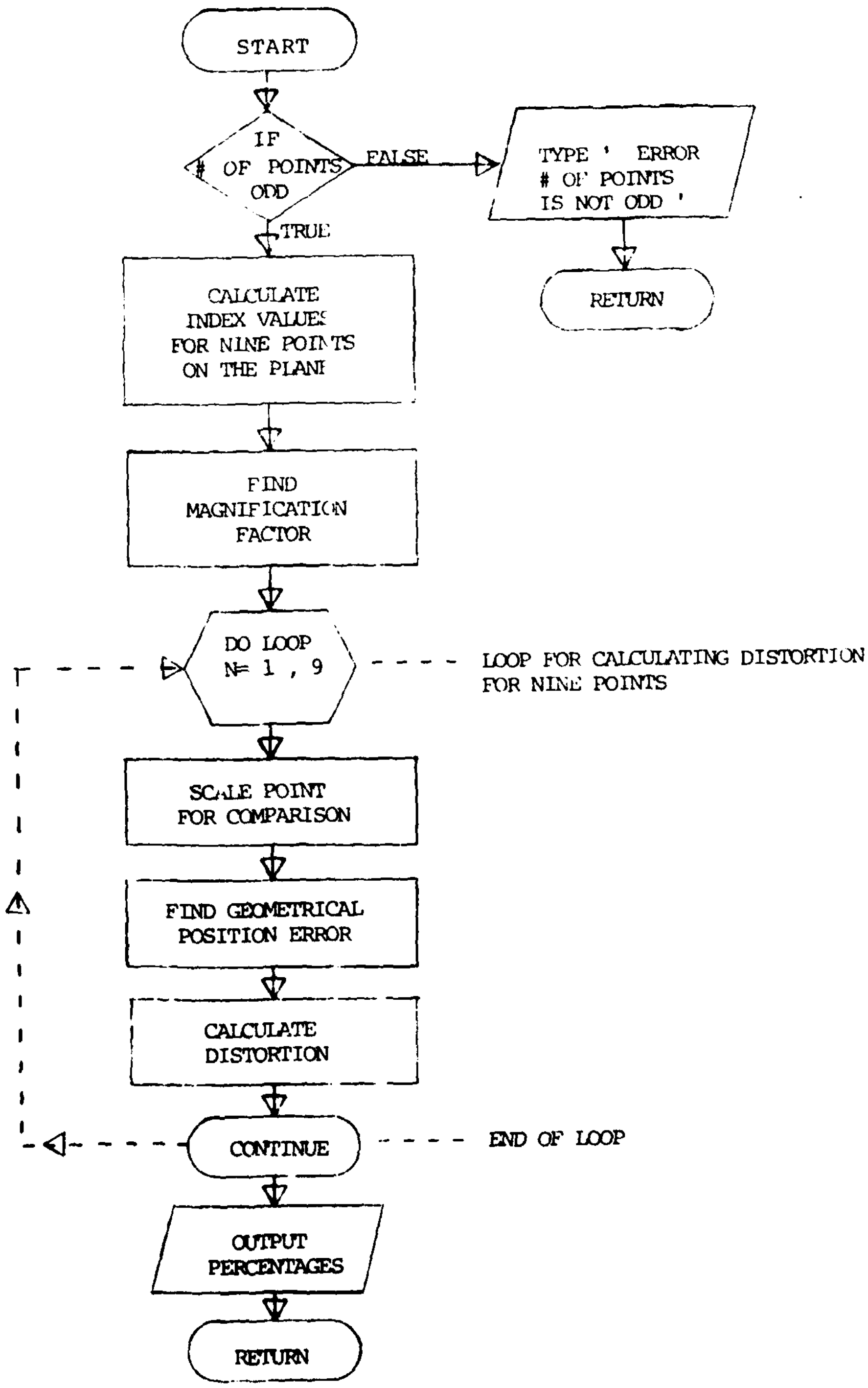

```
            R2 = SIN( FOV2 * .5 * CONVR)
         ENDIF
C
C     FIND RADIAN INCREMENT FOR POINTS ON CIRCLE
C
          RADINCR = 2. * 3.14159265349 / ( NPT - 1 )
C
          DO 100 N = 1,NPT
C
          ARGH = (N - 1) * RADINCR
          CSA  = COS(ARGH)
          SNA  = SIN(ARGH)
C
C     STORE POINTS ON CIRCLE
C
          X1(N) = R1 * CSA
          Y1(N) = R1 * SNA
          X2(N) = R2 * CSA
          Y2(N) = R2 * SNA
C
100      CONTINUE
C
C     DRAW FOV1 WITH LINETYPE 'L1'
C
          CALL SETLINE(L1)
          CALL LINE (X1,Y1,NPT,1,-1,0.,1,0,0)
C
C     DRAW FOV2 WITH LINETYPE 'L2'
C
          CALL SETLINE(L2)
          CALL LINE(X2,Y2,NPT,1,-1,0.,1,0,0)
C
          RETURN
          END
```

SUBROUTINE TBLDIST



```
                C
                C
                C
                C
                C    ********************
                C    *                  *
                C    *    TBLDIST       *
                C    *                  *
                C    ********************
                C
                C
                C    DISTORTION PERCENTAGES AR FOUND ACCORDING TO DEFINITIONS FOUND
                C     IN THE IRE STANDARDS FOR TELEVISION.
                C
                C
                C    THIS SUBROUTINE IS INTENDED TO BE USED WITH DISTORTION ROUTINES
                C     THAT UTILIZE A ONE DIMENSIONAL ARRAY OF POINTS THAT DEFINE
                C     A SET OF POINTS ON A PLANAR SURFACE. THE ALGORITHM DEPENDS ON
                C     BEING SUPPLIED WITH THE 'X' AND 'Y' POINTS FOR DISTORTION
                C     CALCULATIONS AND THE 'XC' AND 'YC' POINTS FOR COMPARISON.
                C
                C         NVERT - NUMBER OF POINTS DOWN THE PLANE
                C         NHORIZ - NUMBER OF POINTS ACROSS THE PLANE
                C
                C    CONSIDERING A RECTANGULAR PLANE , THE POINTS THAT ARE USED ARE:
                C     THE POINTS AT THE FOUR CORNERS, AT THE MIDDLE OF THE OUTER
                C     EDGES, AND AT THE CENTER OF THE PLANE. ( NINE POINTS )
                C     THEREFORE THE VALUES NVERT AND NHORIZ MUST BE ODD.
                C
                C
                C
0001                      SUBROUTINE TBLDIST (X,Y,XC,YC,NVERT,NHORIZ)
                C
0002                      INTEGER*4  I(9)
0003                      DIMENSION PCTDIST(9),X(1),Y(1),XC(1),YC(1)
                C
                C    CHECK NVERT AND NHORIZ FOR ODDNESS
                C
0004                      RNHD2 = NHORIZ / 2.0
0005                      NHD2  = NHORIZ / 2
0006                      RNVD2 = NVERT  / 2.0
0007                      NVD2  = NVERT  / 2
                C
0008                      HN = RNHD2 - NHD2
0009                      VN = RNVD2 - NVD2
                C
0010                      ODD = 0.5
                C
0011                      IF( (HN .NE. ODD) .OR. (VN .NE. ODD) ) THEN
0012                       TYPE * ,' NUMBER OF POINTS IS NOT ODD, TBLDIST EXITED'
0013                       RETURN
```

```
                 ENDIF
        C
        C    CALCULATE INDEX VALUES FOR THE NINE POINTS ON THE PLANE
        C
                 I(1) = 1
                 I(2) = RNHD2 + 0.5
                 I(3) = NHORIZ
                 I(4) = NVD2 * NHORIZ + 1
                 I(5) = I(4) + I(2) - 1
                 I(6) = I(5) + I(2) - 1
                 I(7) = (NVERT - 1) * NHORIZ + 1
                 I(8) = I(7) + I(2) - 1
                 I(9) = I(8) + I(2) - 1
        C
        C    FIND MAGNIFICATION RATIO 'ACONST'
        C
                 PHT  = Y(I(2)) - Y(I(8))
                 CPHT = YC(T(2)) - YC(I(8))
                 ACONST = PHT /CPHT
        C
        C
        C    LOOP FOR CALCULATING PERCENT DISTORTION FOR THE NINE POINTS
        C
                 DO 100 N = 1,9
                        IN = I(N)
                        TX  = X(IN)
                        TY  = Y(IN)
                        TXC = XC(IN) * ACONST
                        TYC = YC(IN) * ACONST
        C
        C
        C    FIND RADIAL DISTANCE FROM POINT ON VIEW PLANE TO POINT
        C     ON VIEW WINDOW 'GPE'.
        C
        C
                 GPE = SQRT((TXC-TX)*(TXC-TX)+(TYC-TY)*(TYC-TY))
        C
        C    CALCULATE DISTORTION
        C
                 PCTDIST(N) = GPE / PHT * 100.
        100    CONTINUE
        C
        C
                 WRITE(4,*),'DISTORTION PERCENTAGES'
                 WRITE(4,2)
        C
                 WRITE(4,3) ,(I(L),L=1,3)
                 WRITE(4,1) ,(PCTDIST(J),J=1,3)
                 WRITE(4,2)
                 WRITE(4,3) ,(I(L),L=4,6)
                 WRITE(4,1) ,(PCTDIST(J),J=4,6)
```

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```
                WRITE(4,2)
                WRITE(4,3) ,(I(L),L=7,9)
                WRITE(4,1) ,(PCTDIST(J),J=7,9)
      C
                RETURN
      C
        1       FORMAT(5X,F6.2,'%',3X,F6.2,'%',3X,F6.2,'%')
        3       FORMAT(4X,I3,6X,I3,6X,I3)
        2       FORMAT(/)
      C
                END
```

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